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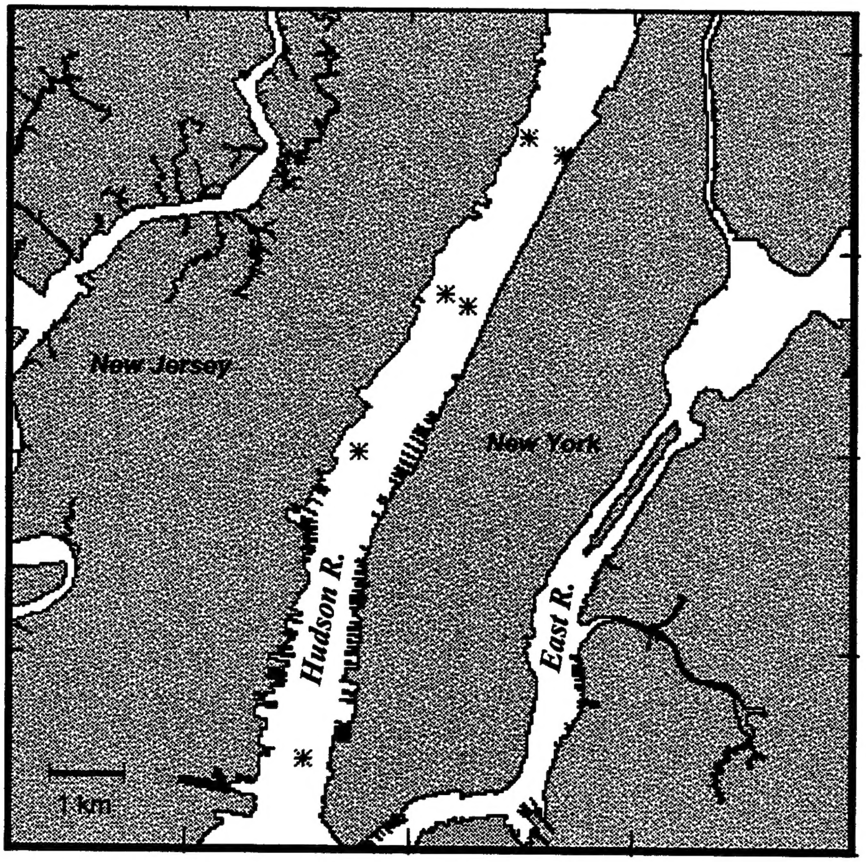
Woods Hole Oceanographic Institution



Stress, Salt Flux, and Dynamics of a Partially Mixed Estuary

by

J.J. Fredericks, John H. Trowbridge, W. Rockwell Geyer,
A.J. Williams 3rd, Melissa Bowen, Jonathan Woodruff

August 1998

Technical Report

Funding was provided by the National Science Foundation
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Approved for Distribution:

Dr. Timothy Stanton

Department of Applied Ocean Physics and Engineering

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SECTION I

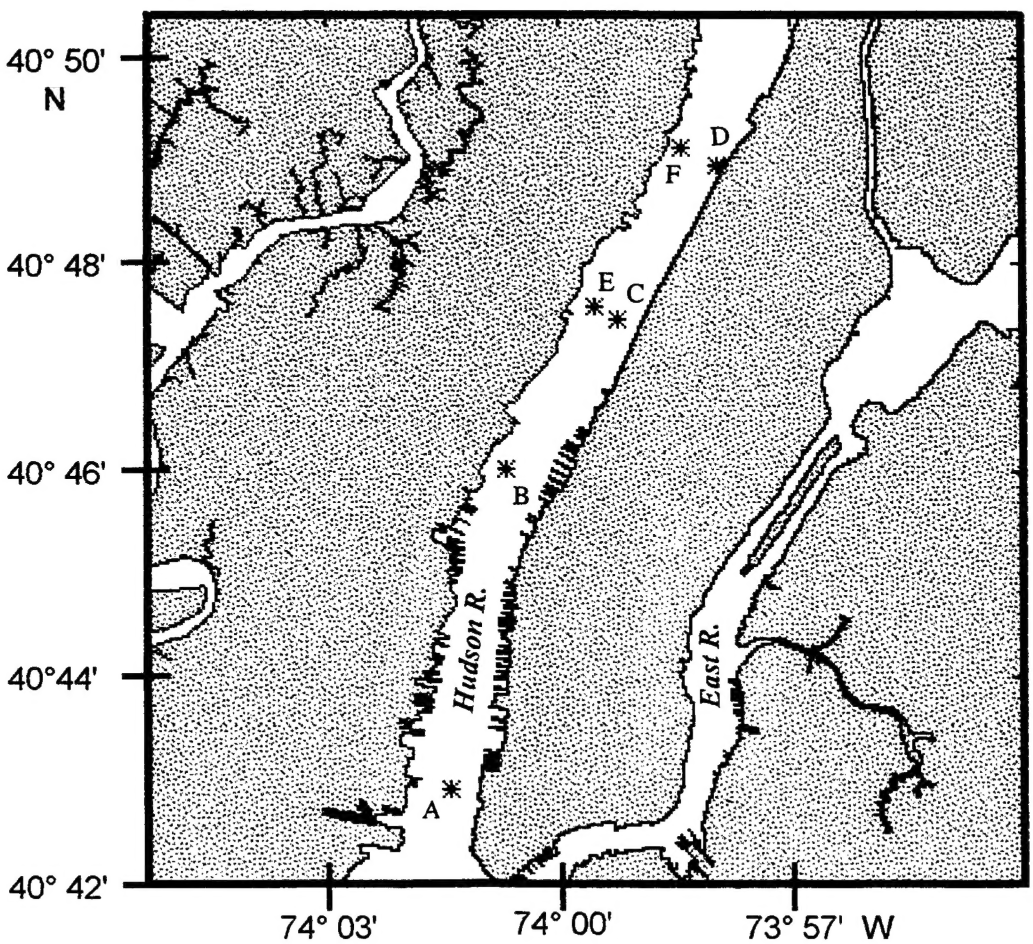
INTRODUCTION

A field study was performed in the lower Hudson River, a partially mixed estuary with a relatively simple geometry (Figure 1), between August and October of 1995. The objectives of the study were (1) to quantify and characterize the turbulent transport of momentum and salt, and (2) to relate the turbulent transport processes to the local and estuary-wide dynamics.

The measurement program consisted of fixed and shipboard components. At a central site, a moored array of temperature-conductivity sensors and optical backscatter sensors (OBS), a bottom-mounted acoustic Doppler current profiler (ADCP), and a bottom-mounted array of acoustic travel-time current sensors (BASS), temperature-conductivity sensors, and OBS sensors resolved the vertical structure of velocity, salinity and turbidity and the near-bottom turbulence structure. Moored and bottom-mounted velocity, temperature, conductivity and pressure sensors at five secondary sites quantified the spatial and temporal variability of velocity, salinity and bottom pressure. Shipboard measurements with an ADCP and a conductivity-temperature-depth (CTD) profiler, accompanied by an OBS sensor, resolved the spatial structure and tidal variability of velocity, salinity and turbidity along several cross-channel and along-channel transects.

This report describes the measurements in detail. Section II describes the instrumentation, Section III describes the deployment and sampling schemes, Section IV describes the data processing, and Section V is a summary of plots of selected data. Section VI documents the data files and Sections VII and VIII give acknowledgments and references.

Figure 1.



SECTION II

INSTRUMENTATION

A. OVERVIEW

This section describes instrumentation developed for the experiment: a quadrapod, six 1-meter tripods, three moorings and the meteorological station, as well as the shipboard data collection system. The tripods and moorings are named A through F, which relate to the deployment sites, as described in Section III and shown in Figure 1.

Table 1. QUADRAPOD, TRIPOD & MOORING INSTRUMENTATION

Temperature (T), Conductivity (C), Pressure (P), Velocity (V), OBS (O)

Inst ID: Site-Type	Height Above Bottom (mab)	Observed Property T	C	P	V	O	Instrument (Model Number)
A-tripod	0.9	T	C	P			Seagauge/26-03 (SG46)
B-tripod	0.9	T	C	P			Seagauge/26-03 (SG41)
C-mooring	depth-2.7	T	C	P	V		S4 "p" (04670927)
	depth-4.3	T	C			O	Seacat (SBE 16-04)/C-1 (SC70) (OBS608)
	depth-6.3	T	C			O	Seacat (SBE 16-04)/C-2 (SC71) (OBS611)
	depth-8.3	T	C			O	Seacat (SBE 16-04)/C-3 (SC73) (OBS420)
	depth-10.3	T	C			O	Seacat (SBE 16-04)/C-4 (SC72) (OBS424)
	depth-12.3	T	C	P			Seacat (SBE 16-04)/C-5 (SC884)
ADCP-tripod	0.9				V		ADCP (SN 0387)
		T	C	P			Seagauge/26-03 (SG45)(PS8202)
BASS-quadrapod	0.3		C		V	O	Seabird-1 (041425) / BASS-1 / OBS-1
		T					Seabird-2 (031718)
	0.6		C		V	O	Seabird-3 (041482*) / BASS-2 / OBS-2
	1.2		C		V	O	Seabird-4 (041481) / BASS-3 / OBS-3
		T					Seabird-5 (031719)
	1.6			P			ParoScientific (59119)
	2.1		C		V	O	Seabird-6 (041462*) / BASS-4 / OBS-4
	2.9	T					Seabird-7 (031720)
			C		V	O	Seabird-8 (648) / BASS-5 / OBS-5
D-tripod	0.9	T	C	P			Seagauge/26-03 (SG49)
	1.1				V		S4 (04911003)
E-mooring	depth-1.0	T	C			O	Seacat (SBE 16-04) (SC68) (OBS409)
E-tripod	0.9	T	C			O	Seacat (SBE 16-04) (SC883) (OBS410)
	1.1				V		S4 (05191143)
F-mooring	depth-1.0	T	C			O	Seacat (SBE 16-04) (SC882) (OBS423)
F-tripod	0.9	T	C	P			Seacat (SBE 16-04) (SC885)
	1.1				V		S4 (18291515)

* Conductivity cells 041462 and 041482 labels had been switched before the first deployment. The labeling was corrected by SeaBird Electronics during the September(1995) calibrations and are shown correctly above.

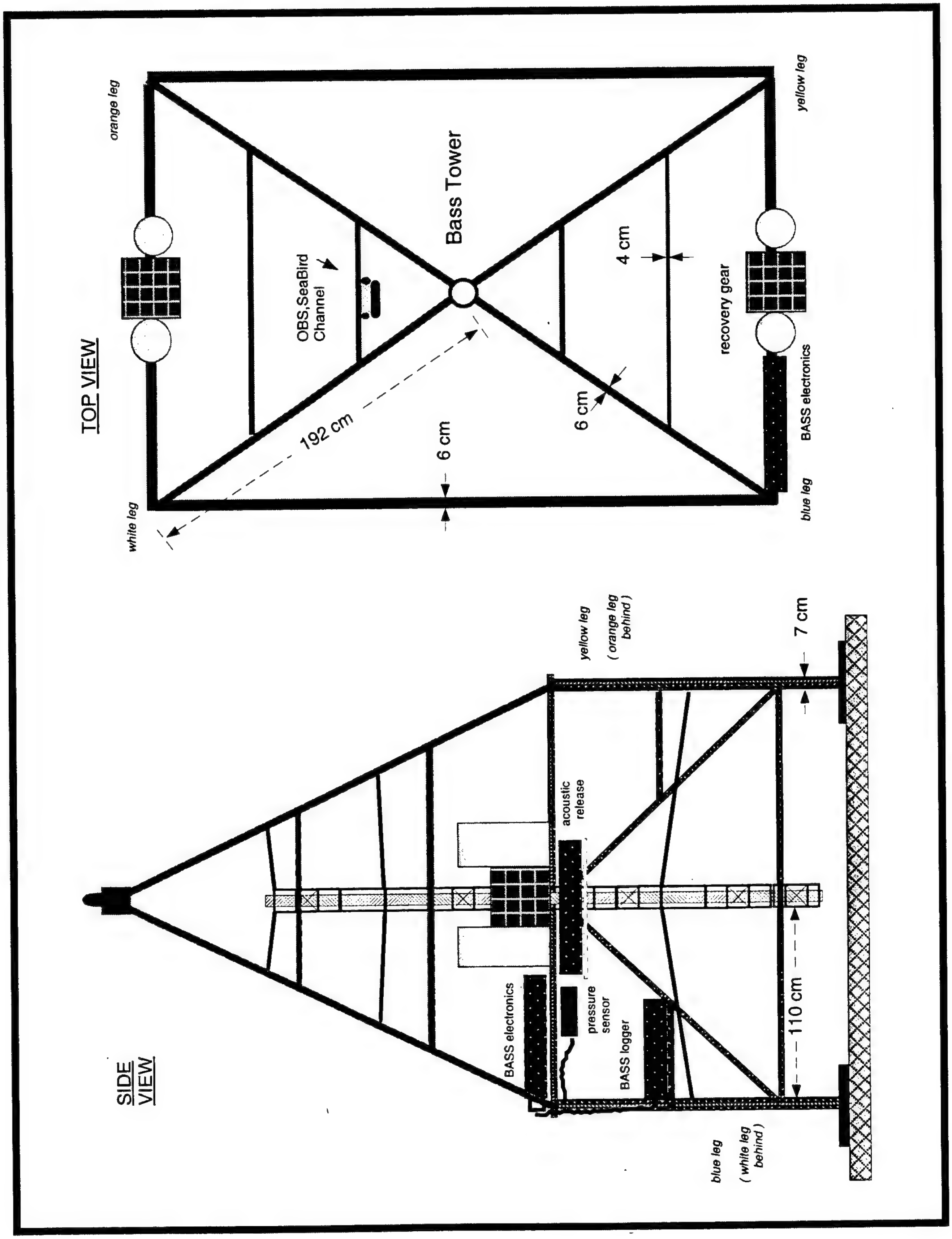


Figure 2a. Side and Top View of Quadrapod

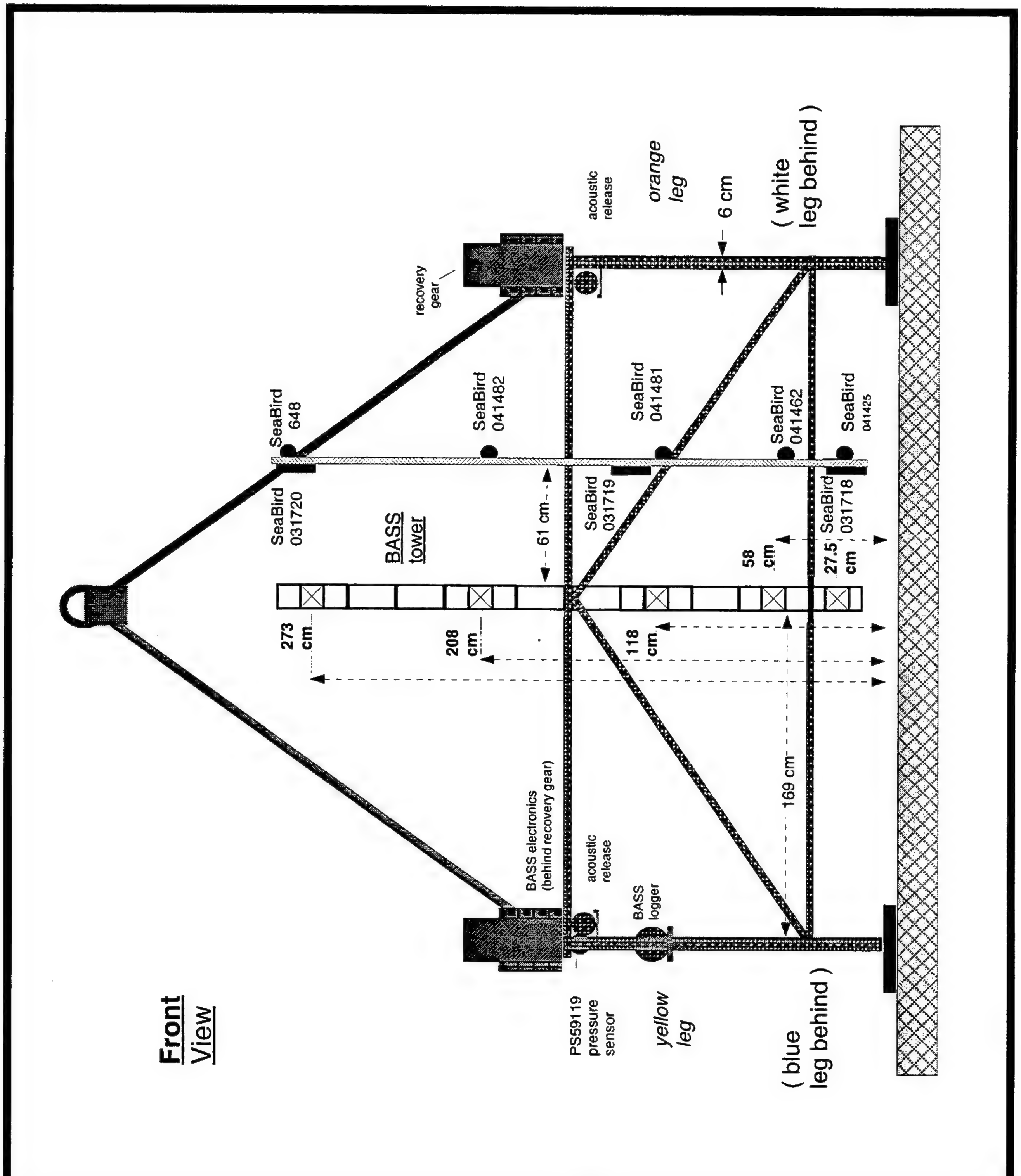


Figure 2b. Front View of Quadrapod

B. QUADRAPOD

A quadrapod was constructed to support five BASS acoustic travel-time velocity sensors (Williams et al., 1987) in a vertical column. The structure also supported five Seabird[1] conductivity sensors, three Seabird temperature sensors, five D & A[2] optical backscatter sensors (OBS), a Digiquartz ParoScientific[3] pressure sensor, a compass and a tiltmeter. (See Table 1 and Figure 2.)

BASS sensors measure differential travel-time of acoustic pulses, along four axes, to compute three dimensional velocity in a 15-cm sample volume. Absolute travel-time was also stored for Path C of each sensor to determine sound speed (Trivett 1991), which is related to salinity, temperature and depth (MacKenzie 1981). High noise levels in the absolute travel-time board prohibit use of the travel time data during the HUDMIX experiment, but the measurements provided an opportunity to resolve critical issues for future development of travel time instrumentation.

The conductivity cells and OBSs were arranged on a channel 0.6 meters away from the BASS tower at the same heights as the BASS sensors and temperature sensors were placed on the same channel at the bottom, middle and top heights. The pressure sensor was approximately 1.7 meters away from the BASS tower, at 1.56 meters above bottom. Counters were used to sample these properties simultaneously (Williams 1995). Pressure cases containing batteries, sensor electronics and data acquisition systems were mounted well away from the sensing volumes.

C. TRIPODS & MOORINGS

Each tripod was equipped with either a Seabird Electronics Seagauge (SBE 26-03) or Seacat (SBE 16-04) sensor to record salinity, temperature and conductivity. Each Seacat had one additional data acquisition port, which was used to accommodate either a strain-gauge pressure sensor or an OBS. See Figure 3 and Table 1 for specific details. A Self-Contained Acoustic Doppler Current Profiler (ADCP), manufactured by RD Instruments,[4] was placed on a tripod to observe horizontal velocity at 1 meter intervals from 1.5 to 15.5 meters above the sensor. InterOcean Systems Model[5] S4 current meters were placed on top of three tripods (D, E and F) to provide horizontal velocity at 1 meter above bottom.

Two tripods (E and F) were equipped with adjacent moorings (Figure 3) to measure conductivity, temperature and optical backscatter 1 meter below the surface.

As seen in Figure 4, the central mooring, or C-mooring, was equipped to observe salinity, temperature and conductivity profiles at 4.3, 6.3, 8.3 10.3 and 12.3 meters below the surface. At 2.7 meters depth, an S4 current meter was equipped to measure conductivity, temperature and pressure, as well as horizontal velocity. OBS cells were mounted to provide estimates of turbidity from depths of 4.3 to 10.3 meters. The Seacat at the bottom of the C-mooring (12.3 meters deep) was equipped with a strain-gauge pressure sensor.

---

[1] Seabird Electronics, Inc., Bellevue, WA 98005

[2] D&A Instrument Company, Port Townsend, WA

[3] ParoScientific, Redmond, WA 98052

[4] RD Instruments, San Diego, CA 92131

[5] InterOcean Systems, Inc., San Diego, CA 92123-1799

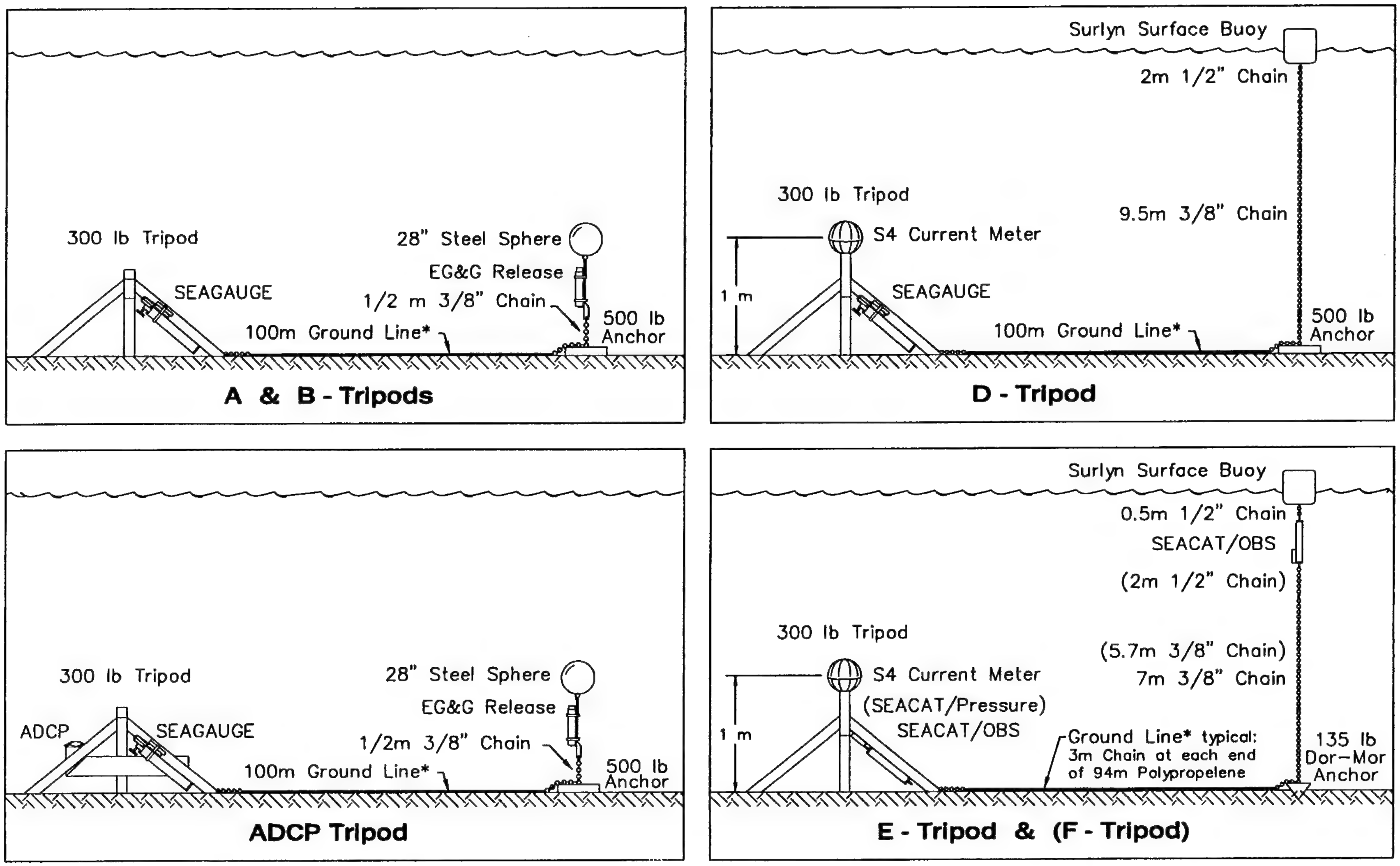


Figure 3. Schematic of Tripods & Moorings (not to scale)

NOTE: The F-Tripod is similar to the E-Tripod. The differences in the F-Tripod are noted in parenthesis.

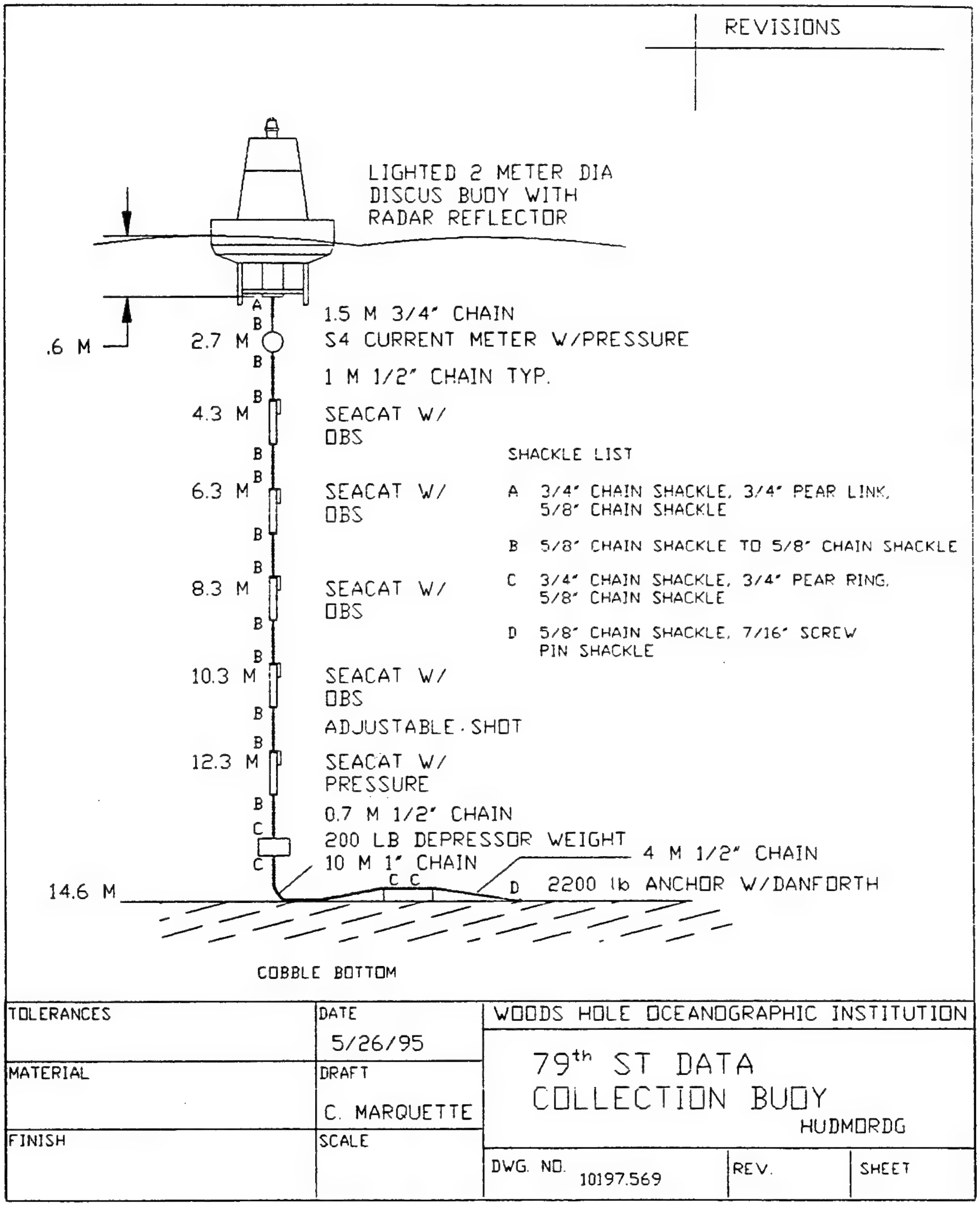


Figure 4. Central Mooring Schematic

NOTE: The S4 current meter was equipped with temperature and conductivity sensors.

D. SHIPBOARD INSTRUMENTATION

The shipboard measurements were performed from the 24' R/V Mytilus (Woods Hole Oceanographic Institution). Instrumentation included:

- an Ocean Sensors[6] CTD profiler (OS200) equipped with an optical backscatterance sensor (D&A Instruments) to measure temperature, salinity, pressure and suspended sediment concentration;
- a 1.2 mHz narrow-band Acoustic Doppler Current Profiler (ADCP, RD Instruments), providing vertical profiles of velocity beneath the vessel;
- a holey-sock drogue, 1-m diameter and 2-m in length, centered at 3.5 meters depth for tracking subsurface currents;
- a Klien (Model 595) sidescan sonar operating at 100 and 500 kHz for recording images of bottom slope variation.

E. METEOROLOGICAL INSTRUMENTATION

Wind speed and direction, air temperature, relative humidity, and atmospheric pressure were collected and processed using a Coastal Environmental Systems [7] Weatherpak-2000 meteorological package.

[6] Ocean Sensors, San Diego, CA 92121

[7] Coastal Environmental Systems, Seattle, WA 98104

SECTION III

DEPLOYMENTS &

SAMPLING SCHEMES

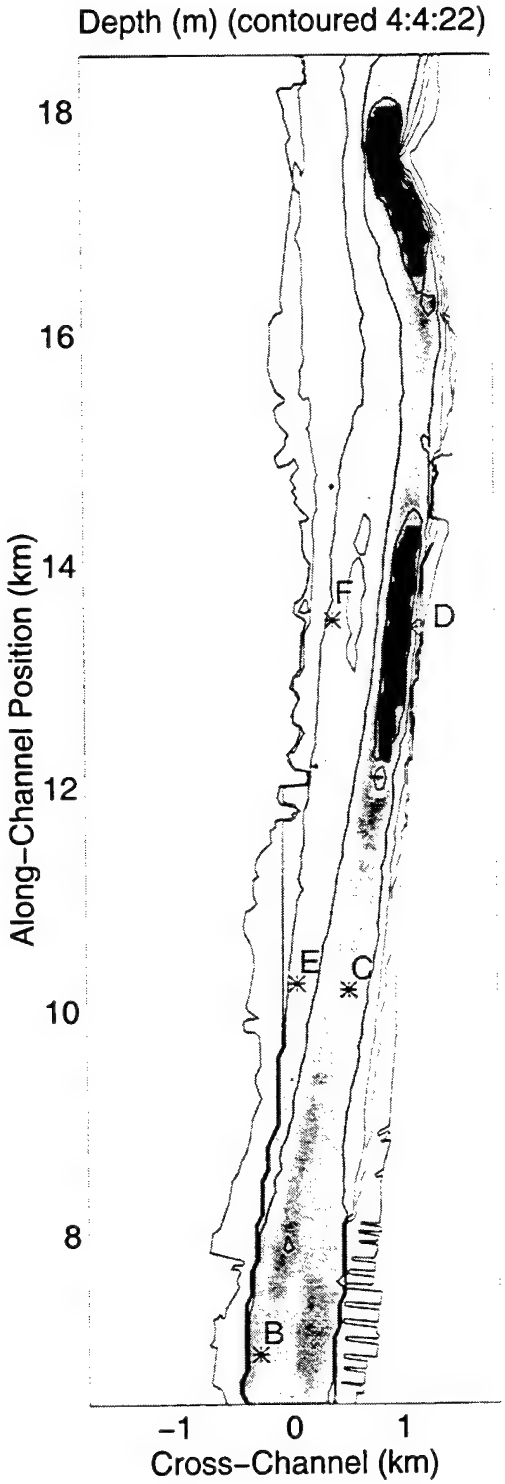


Figure 5. USGS NOS Bathymetry Survey (1934)

A. OVERVIEW

The deployment sites are shown in Figure 5 with the 1934 NOS bathymetry contours. Site A is not shown on this figure and is 3 km seaward of B, as shown in Figure 1. The six tripods and three moorings were onsite from mid-August through the end of October. (See Table 2.) The BASS quadrapod was deployed for two two-week periods, one at the beginning and the other at the end of the study, each spanning one spring-neap tidal cycle.

The C-mooring and tripods A, B and D were deployed in the deepest part of the channel, while Tripods E and F, along with their respective moorings, were deployed on a shelf along the west side of the channel. The BASS quadrapod and the ADCP-Tripod were deployed cross-channel from the central mooring site (Figure 6).

Shipboard CTD surveys were conducted at mooring locations, as well as on along-channel and cross-channel transects, throughout each of the BASS deployment periods. (See Table 3.) Velocity data supplemented the CTD data during transverse and turbidity maximum surveys.

Table 2. SUMMARY OF DEPLOYMENTS (ordered by time of deployment)

Instrument ID	Time In/Out (EDT)	Location Degrees Minutes
C-mooring	8/15/95 17:30 10/26/95 13:10	40° 47.47' N 73° 59.24' W
E-tripod & E-mooring	8/15/95 18:32 10/26/95 9:50	40° 47.92' 73° 59.52'
F-tripod & F-mooring	8/15/95 19:18 10/26/95 10:45	40° 49.20' 73° 58.36'
ADCP-tripod	8/16/95 11:39 10/26/95 09:00	40° 47.49' 73° 59.33'
D-tripod	8/16/95 12:22 10/26/95 12:25	40° 48.96' 73° 57.98'
B-tripod	8/16/95 12:40 10/26/95 08:30	40° 45.97' 74° 00.57'
A-tripod	8/16/95 14:05 10/26/95 07:50	40° 42.92' 74° 01.32'
BASS-quadrapod	8/16/95 16:58 8/30/95 8:53	40° 47.46' 73° 59.19'
Met	8/16/95 17:25 10/26/95 17:10	40° 47.35' 73° 59.02'
BASS-quadrapod	10/17/95 12:05 10/26/95 13:30	40° 47.48' 73° 59.20'

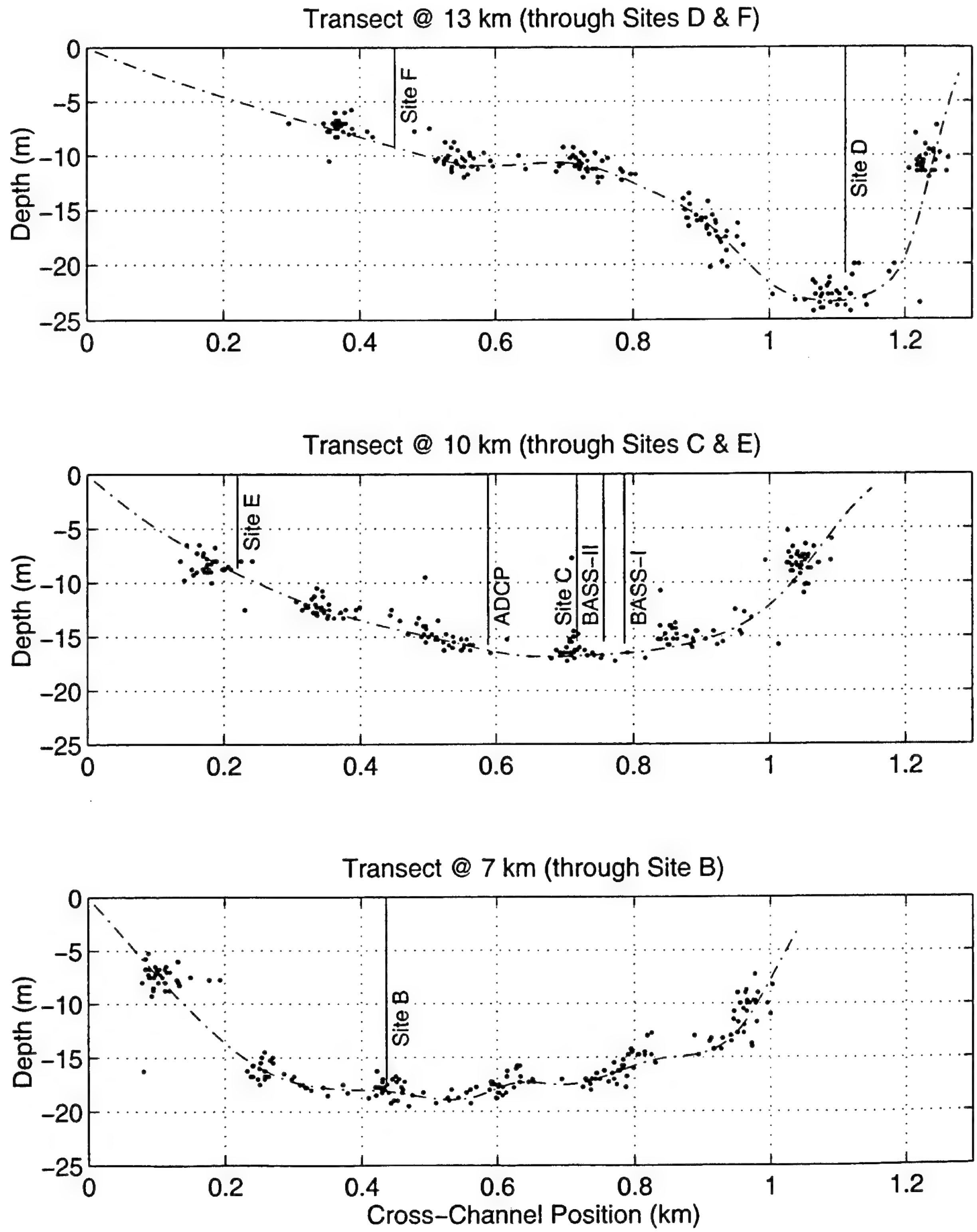


Figure 6. Cross-channel site locations are shown with CTD depths (dots) and estimate of bottom-profile (dash-dot).

B. QUADRAPOD

During August, 1995, the quadrapod was tested in 10 meters of water off the coast near the Woods Hole Oceanographic Institution. These data are not presented in this report.

For the Hudson River deployments, care was taken to align the front of the quadrapod with the primary component of the tidal flow. This minimized flow disturbance from the structure and the instrument pressure cases. Pre- and post-cruise zeroes were conducted by wrapping the sensing volume in plastic and dipping the instrument from the dock.

First deployment:
Pre-deployment zeroes were taken 04:00 - 05:00 GMT on 8/16/95. The quadrapod was deployed on August 16, 1995, approximately 100 meters east of the Central mooring site (C). The orientation was: compass (231° ± 1°), pitch (-0.44° ± 0.09°), roll (-2.38° ± 0.06°). The depth from the pressure sensor was 15.55 ± 0.44 meters. Every 10 minutes, three minutes of data were recorded (1230 samples at 160 millisecond intervals). Post-deployment estimates of zeros were taken from 13:50 - 16:40 GMT on 8/30/95.

Second deployment:
Pre-deployment estimates of zeros were taken from 17:30 - 18:00 GMT on 10/16/95. The instrument was deployed October 17, 1995, at the same location. The quadrapod was not oriented as closely to the tidal flow (13° from Deployment I): compass (218° ± 4°), pitch (-2.29° ± 0.06°), and roll (2.58° ± 0.02°). The depth from the pressure sensor was 15.38 ± 0.50 meters. Every 10 minutes, six minutes of data were recorded (2220 samples at 170 millisecond intervals). Post-deployment estimates of zeros were taken on 10/26/95 (19:51 GMT).

C. TRIPODS & MOORINGS

The C-mooring was deployed at the deepest part of the channel along the central transect of the experiment region. The Seacats with OBS sensors sampled every 5 minutes; the Seacat with the pressure sensor sampled every 20 minutes; and the S4 with pressure recorded a three minute average every 20 minutes.

Tripods A, B and D were also placed in the deepest cross-channel location at positions along the river (Figure 1). The Seagauge sensors were programmed to record a 20 minute average every 20 minutes. The S4 recorded 3 minute averages of 2Hz data every 10 minutes.

Tripods E and F, with the attached moorings, were placed on a shelf on the western side of the channel. The Seagauges on the tripods sampled every 20 minutes, while the S4s recorded 3 minute averages of 2Hz data every 10 minutes. The Seacat on the E-mooring sampled every 5 minutes and the Seacat on the F-mooring sampled every 20 minutes.

The ADCP tripod was deployed approximately 140 meters west of the central mooring site and was configured to provide 15 one-meter depth bins centered at 1.5 to 15.5 meters above bottom. The ADCP was set up to record 9 minute averages every 10 minutes (with 200 pings/ensemble). The Seagauge (with pressure) recorded 20 minute averages every 20 minutes.

D. SHIPBOARD OBSERVATIONS

The CTD was hand-lowered at approximately 1 m/s to within 0.25 meters of the bottom during each cast. A wooden dowel was used to prevent the sensors from touching the bottom. The sampling rate was 10 Hz, yielding a vertical resolution of 10 cm. The ADCP transducer was fixed to the side of the ship at 0.3-m depth, providing velocity data at 1-m intervals from 1.3m below the surface to within 15% of the total water depth. The last 15% was contaminated by the bottom return. Velocity relative to the bottom was determined by bottom

tracking.

Five types of surveys were conducted throughout the experiment: transverse, long, longitudinal, turbidity maximum, and yo-yo anchor stations. (See Table 4.)

Transverse sections were conducted approximately hourly during each observation period, sampling across the channel at the central mooring site and about 3 km upstream and downstream of the central mooring (at Sites B and D/F). These surveys included ADCP velocity, as well as CTD and OBS profiles.

Four long surveys were conducted from the Battery (0 km) to approximately 1psu salinity (61 - 110 km).

Four detailed longitudinal sections were conducted along approximately 28 km of the river section centered around the Central Mooring site (Site C), following the deepest part of the channel.

Four local surveys between the central mooring site and the northern transect (Site D/F) were conducted primarily on the western bank to 10 meters to study the turbidity maximum.

Two yo-yo casts were conducted at anchor stations to detect internal waves, but have not been processed to date.

Table 3. SUMMARY OF SHIPBOARD SURVEYS

Date (EDT)	Day #	Survey Type	Along-Channel Location
8/15/95 16:18	1	Side Scan Sonar	10.3 ± 0.2 KM
8/17/95 8:15 - 19:05	3	(4) longitudinal sections	-4 to 25 KM
8/18/95 7:05 - 19:10	4	(10 each) transverse sections	@ 7, 10 & 14 KM
8/20/95 10:28 - 17:35	6	1st long survey	0 to 96 KM
8/21/95 8:59 - 19:13	7	1st turb. max survey	11 to 13 KM
8/22/95	8	Side Scan Sonar	12 ± 2 KM
8/23/95 8:20 - 18:52	9	2nd turb. max survey	11 to 13 KM
8/24/95 7:21 - 16:57	10	3rd turb. max survey	11 to 13 KM
8/25/95 7:27 - 18:03	11	4th turb. max survey	12 to 13 KM
8/27/95 7:53 - 17:36	13	(4) longitudinal sections	-4 to 24 KM
8/28/95 7:28 - 19:37	14	(11 each) transverse sections	@ 7, 10 & 14 KM
8/29/95 9:14 - 13:01	15	2nd long survey	0 to 110 KM
10/16/95 16:34 - 20:36	16	3rd long survey	0 to 106 KM
10/17/95 7:45	17	yo-yo anchor station	
10/18/95 7:38 - 17:43	18	4 longitudinal sections	-4 to 24 KM
10/19/95 7:40 - 19:52	19	(11 each) transverse sections	@ 7, 10 & 14 KM
10/20/95 7:49 - 19:07	20	4 longitudinal sections	-4 to 24 KM
10/21/95 7:32 - 14:27	21	(4) transverse sections	@ 7, 10 & 14 KM
10/22/95 15:34 - 01:45	22	3 longitudinal sections	-4 to 24 KM
10/23/95 7:27 - 18:53	23	(10-11 each) transverse sections	@ 7, 10 & 14 KM
10/24/95	24	yo-yo anchor station	
10/25/95 11:38 - 14:20	25	4th long survey	0 to 61 KM

D. METEOROLOGICAL STATION

The WeatherPak was installed at the 79th Street Boat Basin, which was along the transect of the ADCP tripod, BASS quadrapod and the central mooring. The unit was strapped to along-channel pilings, with the sensing volume at approximately 4 meters above the mean water level. Five (5) minute averages every 5 minutes were recorded.

SECTION IV

DATA PROCESSING

A. OVERVIEW

This section documents the details of data processing. Section B describes the processing of data from the quadrapod; Section C from the moorings and tripods; Section D from the shipboard systems; and Section E from the meteorological data.

B. BASS QUADRAPOD

BASS Velocity

Data were unpacked, corrected for zeros (Morrison, 1993) and converted into along (up channel) and cross channel (toward New Jersey) velocity.

Table 4. Summary of Determination of BASS Zeros (m/s)

ACM:Axis/Pod	8/15/95 mean	8/31/95 mean	10/16/95 mean	10/26/95 mean	8/95 used	10/95 used
1:Axis A/1	-0.004	-0.005	-0.004	-0.005	-0.005	-0.005
2:Axis B/1	-0.011	-0.001	*BAD	BAD	BAD	BAD
3:Axis C/1	-0.000	0.003	0.000	0.002	0.000	0.000
4:Axis D/1	-0.006	-0.001	-0.001	-0.002	-0.004	-0.001
5:Axis A/2	0.002	0.008	0.000	-0.000	BAD	BAD
6:Axis B/2	0.003	0.006	0.002	0.002	0.005	0.002
7:Axis C/2	-0.001	-0.002	0.000	-0.003	-0.002	0.000
8:Axis D/2	0.002	0.000	0.002	0.003	0.002	0.002
9:Axis A/3	0.007	0.009	0.012	0.008	0.008	0.012
10:Axis B/3	0.004	-0.008	BAD	-0.006	0.000	0.000
11:Axis C/3	-0.007	-0.007	-0.012	-0.010	-0.007	-0.012
12:Axis D/3	-0.003	0.010	BAD	BAD	BAD	BAD
13:Axis A/4	-0.006	-0.004	BAD	BAD	-0.005	BAD
14:Axis B/4	0.008	0.007	0.000	0.004	0.007	0.000
15:Axis C/4	0.005	0.004	0.003	0.005	0.004	0.003
16:Axis D/4	-0.010	-0.011	-0.003	-0.007	-0.010	-0.003
17:Axis A/5	-0.002	-0.003	-0.004	-0.004	-0.002	-0.004
18:Axis B/5	0.002	0.006	-0.001	0.000	0.000	-0.001
19:Axis C/5	0.002	0.006	0.001	0.004	0.004	0.001
20:Axis D/5	-0.001	-0.002	0.001	BAD	-0.002	0.001

* (BAD) These axes had no data or frequent periods of bad data.

Each sensor, or pod, is numbered 1 to 5 (bottom to top). Some axes did not work properly, or at all, and were reconstructed from the remaining three axes of the affected pod: Deployment I & II: Axis B (Pod 1) Axis A (Pod 2), Axis D (Pod 3); Deployment II (only): Axis A, Pod 4.

The existence of an intermittent problem in the BASS electronics caused the recorded velocities to jump to values far from the tidal signal. These data were replaced with NaNs. Fewer than 4% of the bursts had more than 4% of the burst flagged bad because of this problem.

Another condition existed around 8/26/95 when severely reduced velocities persisted over a few tidal cycles, varying amongst sensors 1 through 3 (moving after tidal changes). These periods were flagged as NaN in the

burst averaged and hourly averaged data only.

Quadrapod Pressure, Conductivity & Temperature

These data were all collected using counters (Williams 1995). For reasons not understood, this sampling technique introduced a noise floor which limits the effective sampling frequency to a factor of 10 lower than the Nyquist frequency. These problems were more severe during the October deployment.

Sediment trapped in the conductivity cells caused the salinity to appear lower than actual conditions; therefore, small vertical gradients in salinity may be unreliable.

For the second deployment (October 1995), it was apparent that the top-most SeaBird conductivity cell was faulty and is not included in the data set.

Conductivity and temperature data were converted to world units using coefficients from the September, 1995, SeaBird calibrations.

Modifications by ParoScientific to their pressure gauges provide temperature frequencies to be used to correct the pressure signal for temperature effects. During the Hudmix experiment, the pressure sensor temperature frequency was not recorded, so a lookup table of temperature and temperature frequency was obtained from ParoScientific. SeaBird temperature was used with the lookup table (tcal.mat) to correct the pressure for temperature.

Quadrapod OBS

These data show strong tidal fluctuations but have not been calibrated with sediment concentration, and remain as counts. The processed data had each sensor's daily observed baseline subtracted (in counts), as follows: all counts greater than 60000 were discarded as outliers; then, for each sensor, the 20th percentile of the cumulative frequency distribution was identified and subtracted from the data; finally, all values less than zero were assigned to be zero. An approximate calibration based on comparison with the shipboard OBS measurements (8/28 and 10/23/95), which were calibrated against water samples, is a linear relationship between counts and sediment concentration, with no offset, and with the maximum observed concentration equal to the maximum shipboard concentration: for Deployment I, 800 counts is roughly 60 mg/l; for Deployment II, 4000 counts is roughly 200 mg/l.

C. MOORED & TRIPOD DATA

Instruments were synchronized by the application of appropriate time offsets for each instrument. Hourly averages were computed from measurements by applying a one-hour boxcar filter and interpolating values to obtain on-hour estimates.

Tripod Salinity

As seen in the quadrapod sensors, sediment accumulation in the tripod conductivity sensors caused significant errors in salinity. Ad hoc corrections were made to yield stable stratification and to minimize differences from the shipboard CTD. Apparent anomalies in salinity were removed; then, salinity from B-tripod was detrended, based on a comparison with the A-tripod and C-mooring data; and salinity from D-tripod was detrended (piecewise), based on comparison with C-mooring data. Fouling of the conductivity cells in the bottom sensors make the use of near-bottom vertical salinity gradients unreliable, but data can confidently be used to document tidal variability.

Tripod Pressure

Seagauge pressure data were corrected for atmospheric pressure with the time series of barometric pressure from the met data. Pressure data from the central mooring Seacat and from the F-tripod Seacat were detrended.

ADCP Velocity

Data were rotated into along and across channel coordinates by determining the angle of maximum variance (46.1° from Magnetic North). From the tilt and compass, it can be seen that the ADCP tripod was disturbed on October 23 (Day 295). First it moved near the maximum ebb flow and then, 6 hours later, near maximum flood flow. The ADCP velocities during the six hour time period appeared faulty, indicating flow obstruction, and were removed from the data set.

S4 Velocity

S4 data from the central mooring, D Tripod, E Tripod and F Tripod were rotated to along-channel velocity components, based on the angle of maximum variance: 45.2°, 44.7°, 54.3° and 55.2° from Magnetic North, respectively.

Tripod and Moored OBS Data

The moored OBS data (volts) were noisy, with drift problems, and have not been calibrated; they are subsequently not discussed in this report.

D. SHIPBOARD DATA

CTD Data

Until August 25, the salinities from the CTD are consistent with the moored salinity sensors. After August 25, CTD salinity measurements appear 0.8-1 psu too low. This is most likely due to damage to the sensor during near-bottom sampling. Data from each CTD cast was vertically averaged into 25-cm increments.

ADCP Data

Current meter data collected from the shipboard ADCP were converted into along and across channel components using the angle of maximum variance to determine the along channel direction. The shipboard ADCP velocity measurements were interpolated in space to obtain the velocities corresponding to the CTD's vertically averaged data. In addition, high frequency (10-second to 1-minute period) fluctuations in the ADCP velocities due to bottom tracking errors were filtered out by applying a sixth order polynomial fit to the data. All measurements were graphically analyzed to remove outlying data points.

OBS Data

The OS200/OBS hand profiler was calibrated using the OBS on the small tripod called Gafanhoto, used in a companion study of sediment transport, which was calibrated against water samples. In the lab comparisons, the gain of the two instruments over a range of concentrations was within 2%. Shipboard OBS data are documented in Orton (1995).

E. METEOROLOGICAL DATA

Met data were converted from wind speed and direction to oceanographic fluid velocity, using the angle of maximum variance (19.6° from Magnetic North) to rotate northward and eastward flow into along and across channel velocity.

SECTION V

DATA SUMMARY

A. OVERVIEW

In this chapter, time series and contours of the data provide an overview of sampling durations and data ranges. The plots are grouped by deployment type: quadrapod (Section B), tripods and moorings (Section C), shipboard data contours (Section D) and meteorological data (Section E).

Section F contains comparisons of ADCP velocity, temperature and salinity with those of BASS at the same time and depth, together with a comparison of ADCP temperature and salinity with corresponding central mooring observations. The 79th Street wind velocities are compared with the National Data Buoy Center (NOAA) buoy wind velocity.

B. QUADRAPOD

Time series of each of the quadrapod deployments are presented in figures 7 - 12.

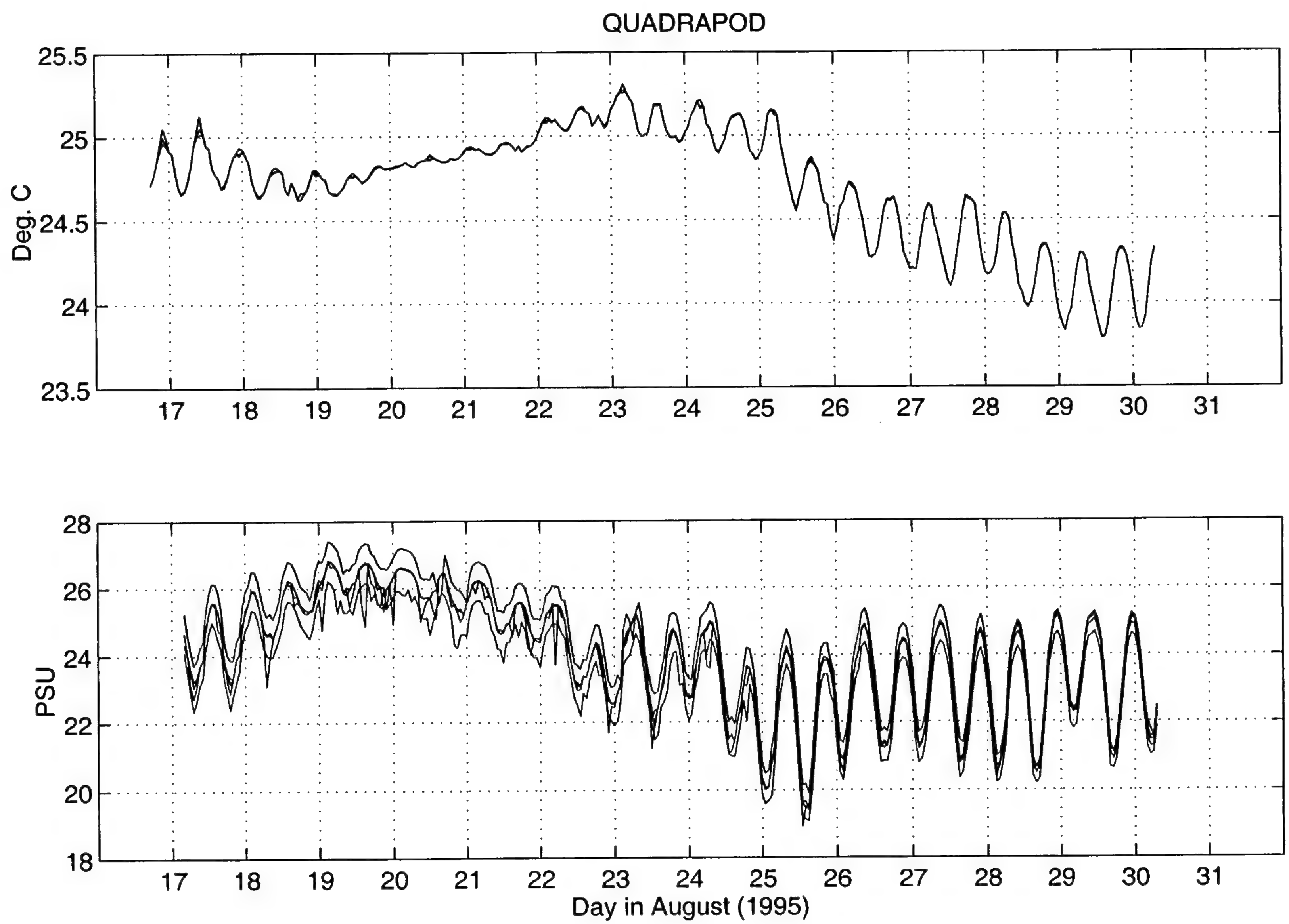


Figure 7. Quadrapod: Temperature & Salinity (Deployment I)

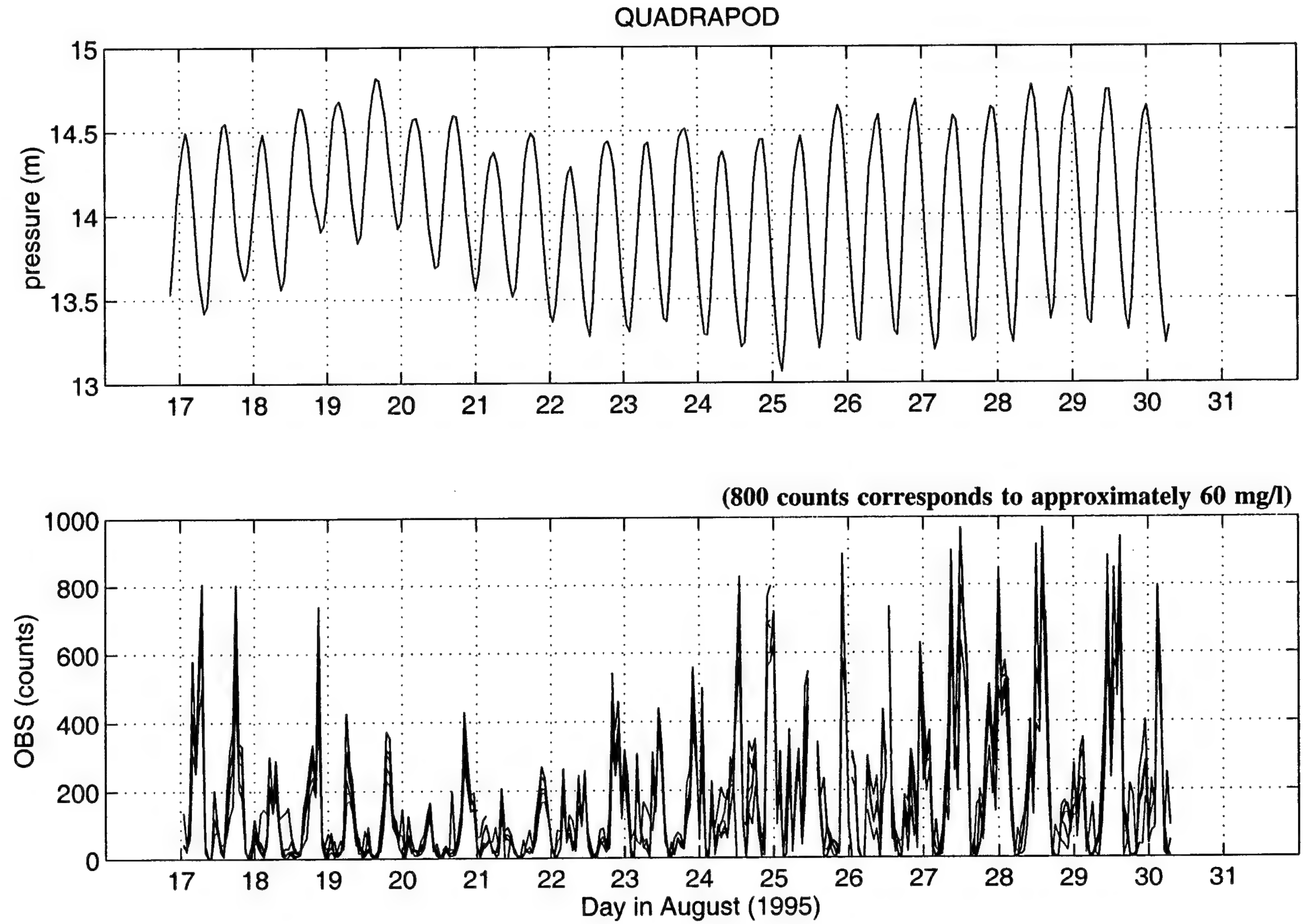


Figure 8. Quadrapod: Pressure & OBS (Deployment I)

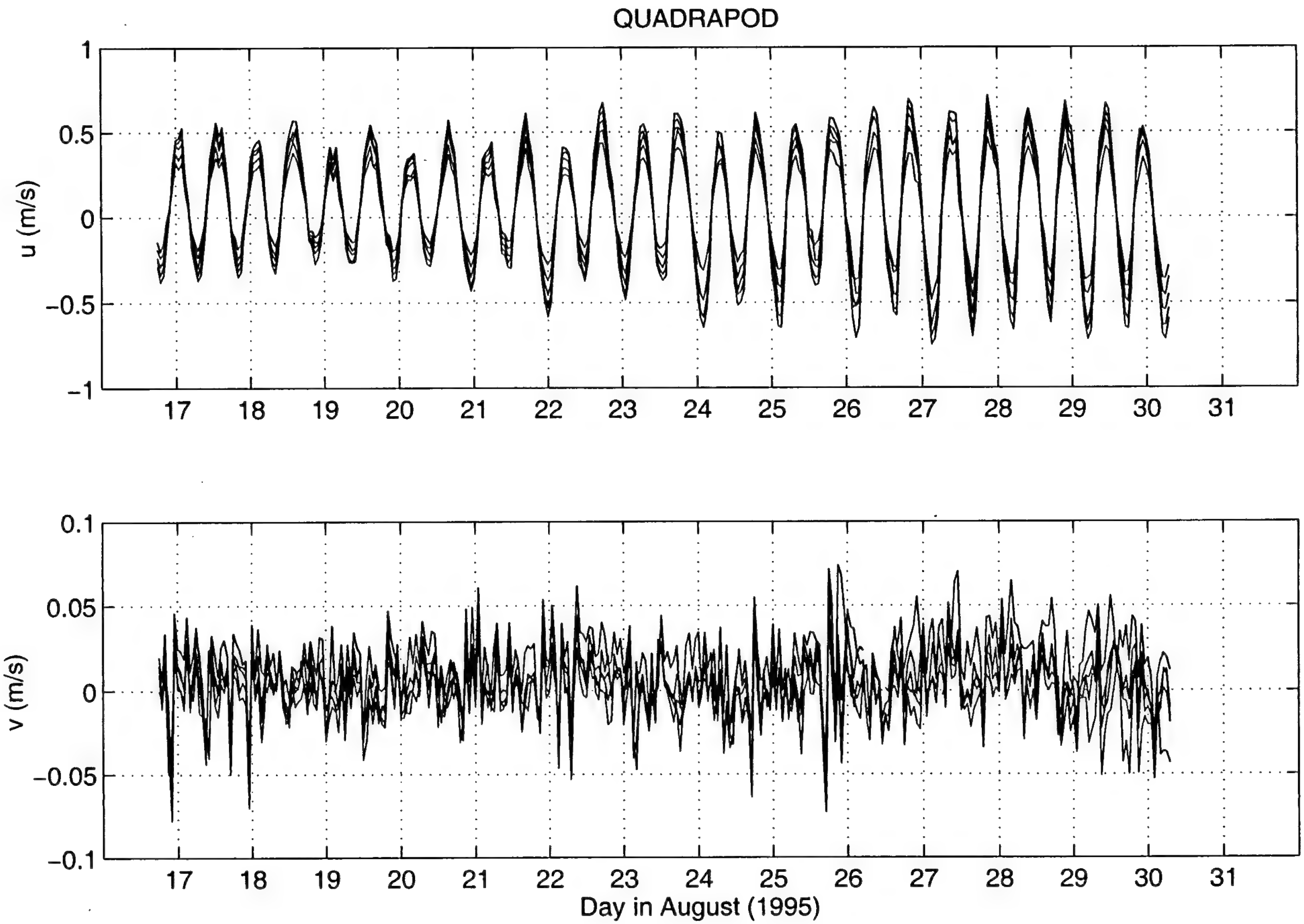


Figure 9. Quadrapod: Horizontal Velocity (Deployment I)

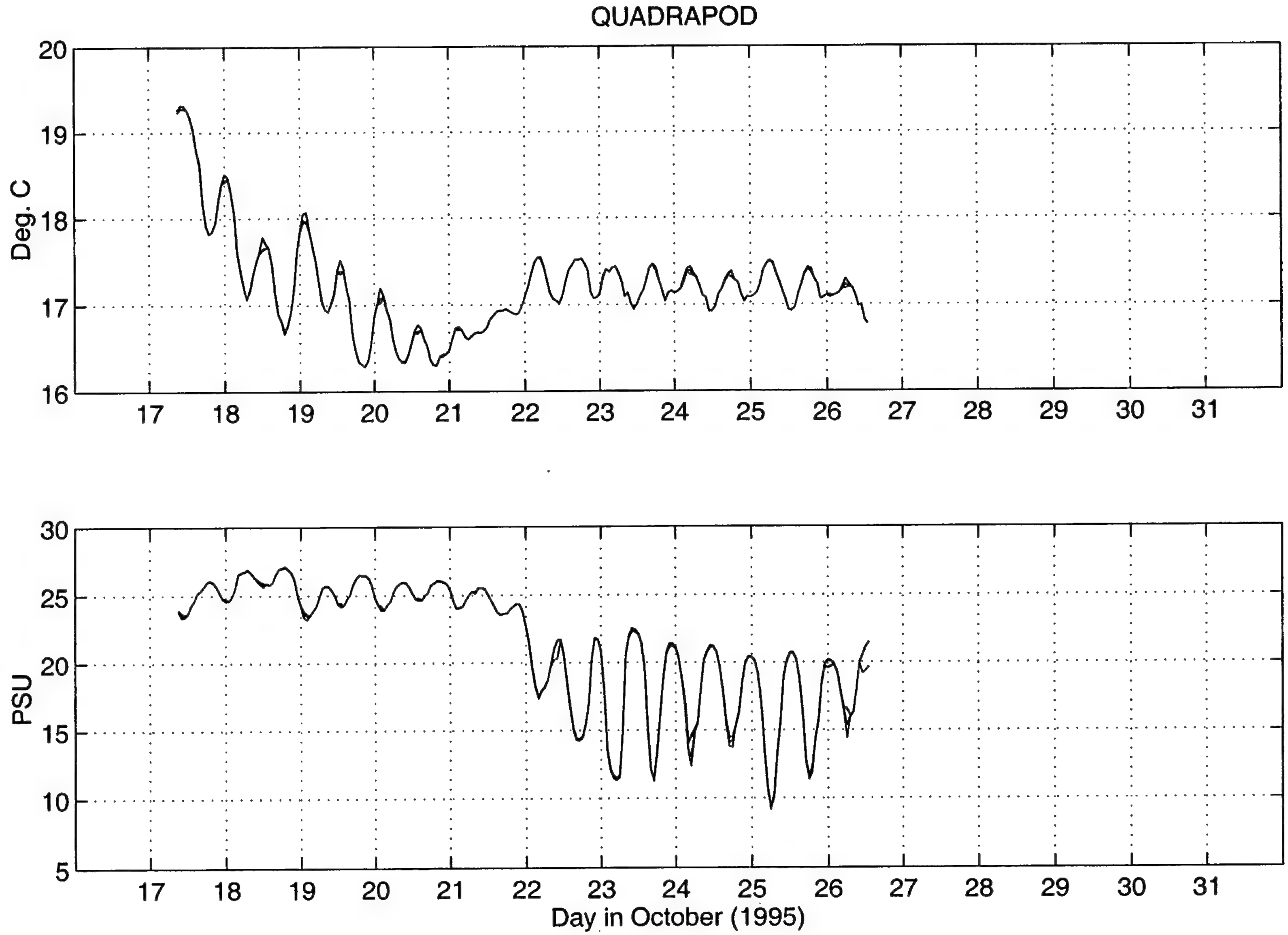


Figure 10. Quadrapod: Temperature & Salinity (Deployment II)

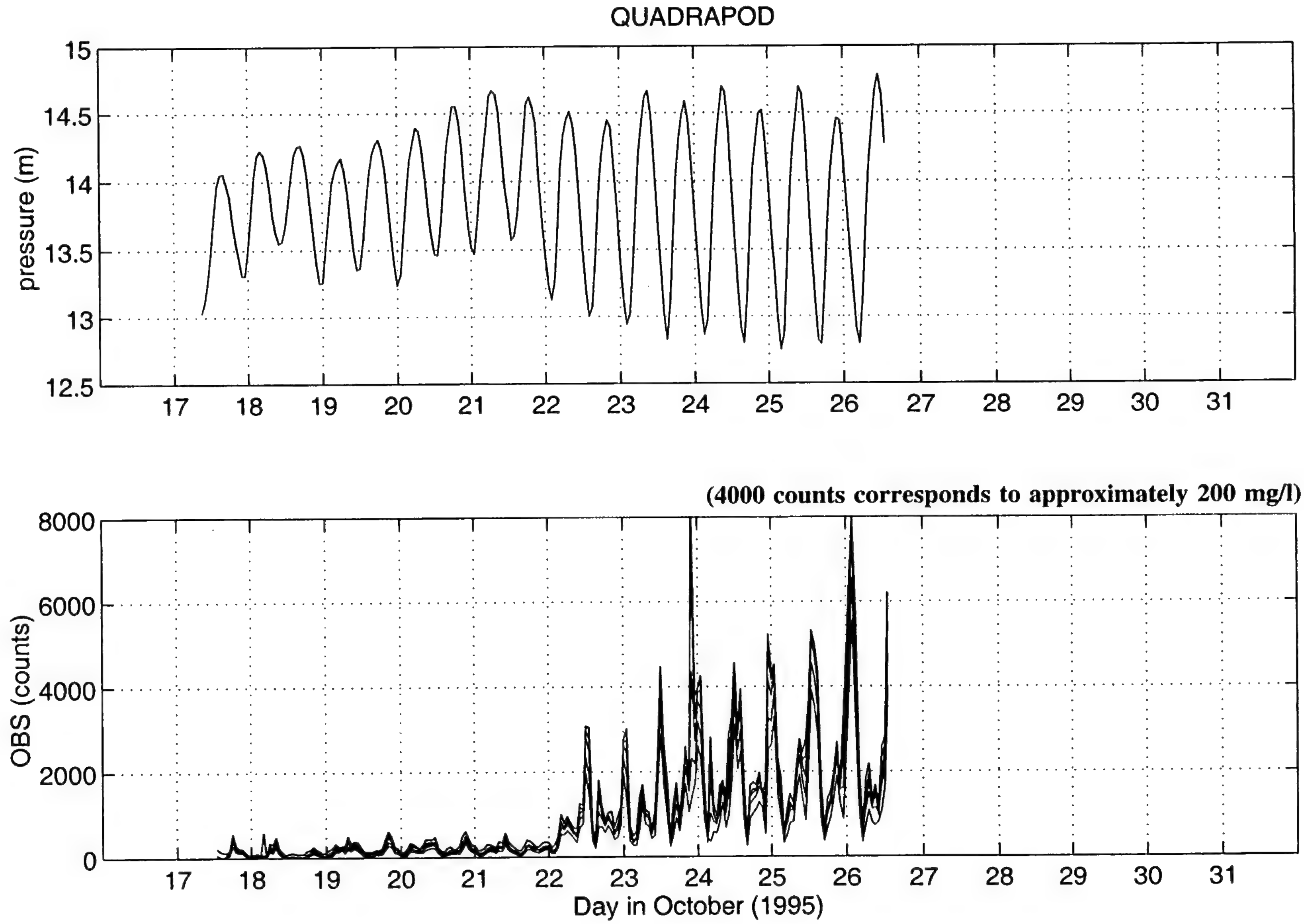


Figure 11. Quadrapod: Pressure & OBS (Deployment II)

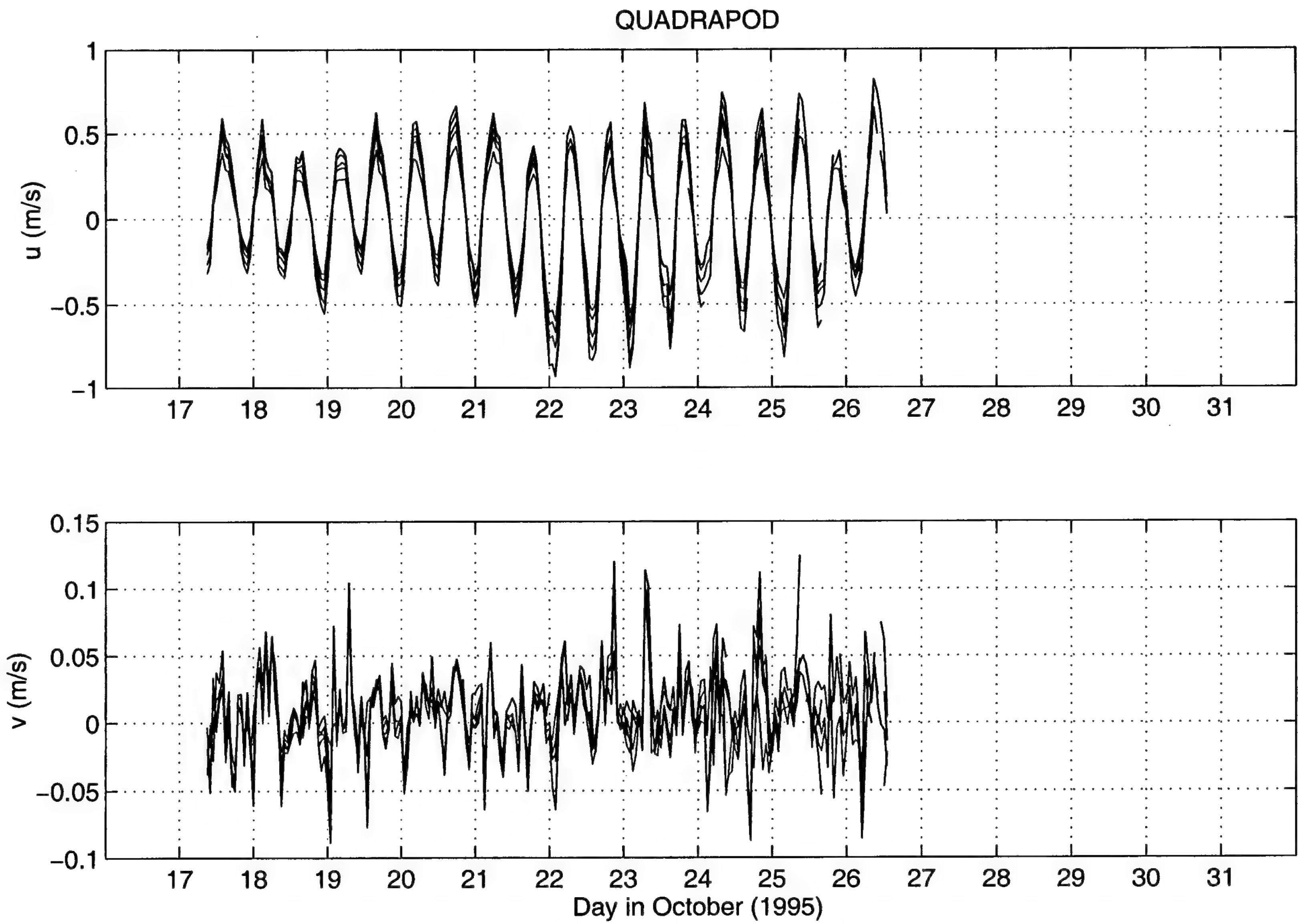


Figure 12. Quadrapod: Horizontal Velocity (Deployment II)

C. TRIPODS & MOORINGS

Time series of the tripod and mooring data are presented in figures 13 - 34.

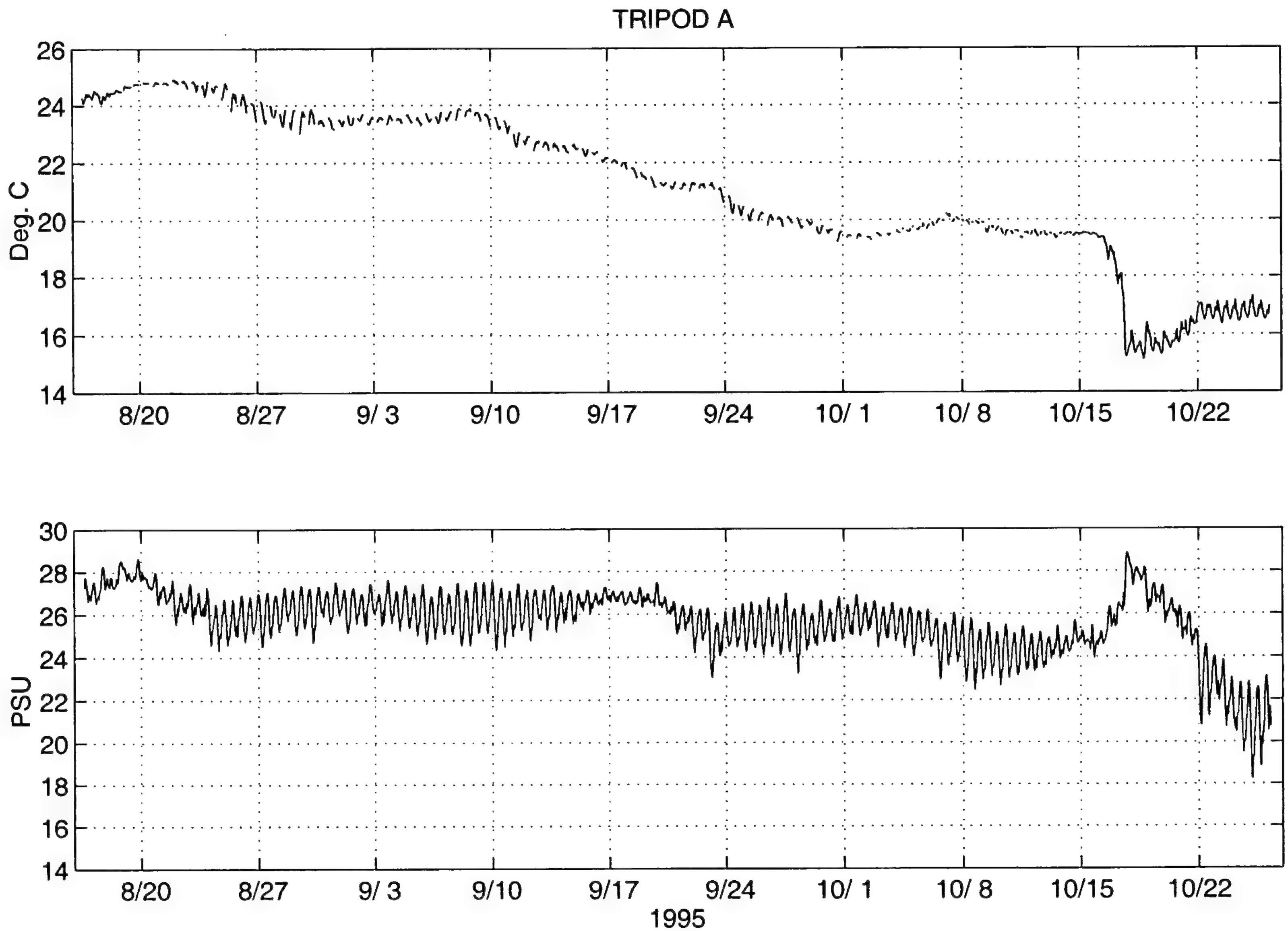


Figure 13. Tripod A: Temperature & Salinity

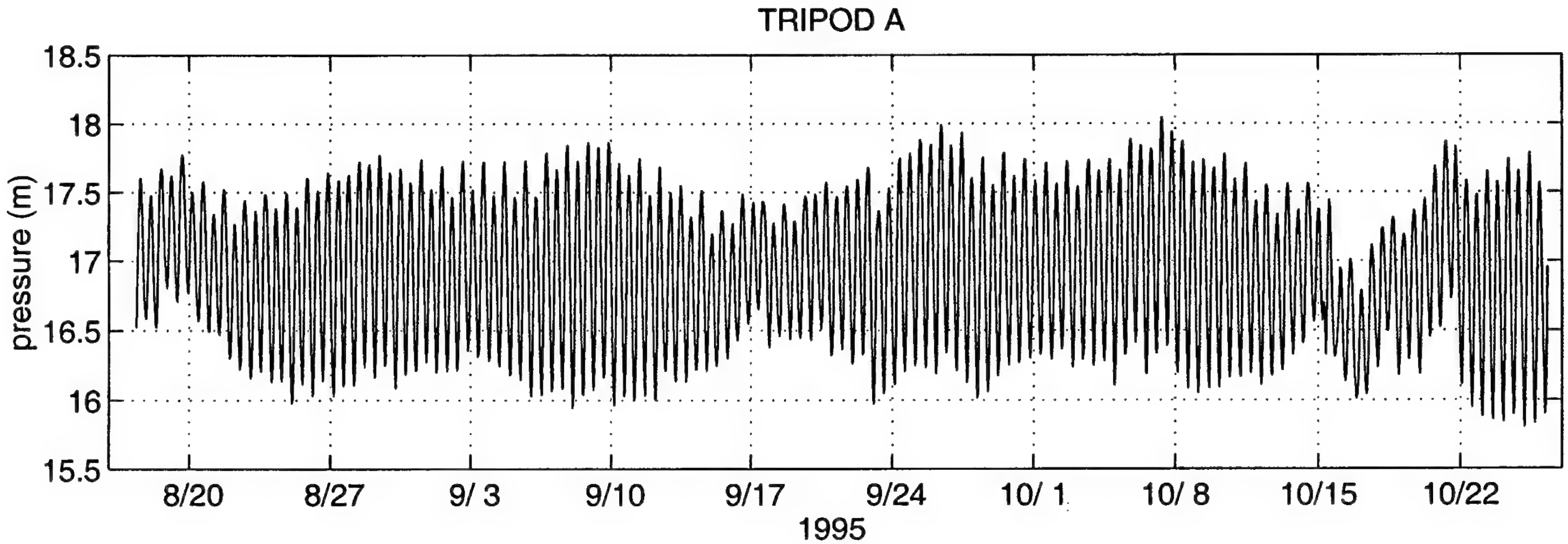


Figure 14. Tripod A: Pressure

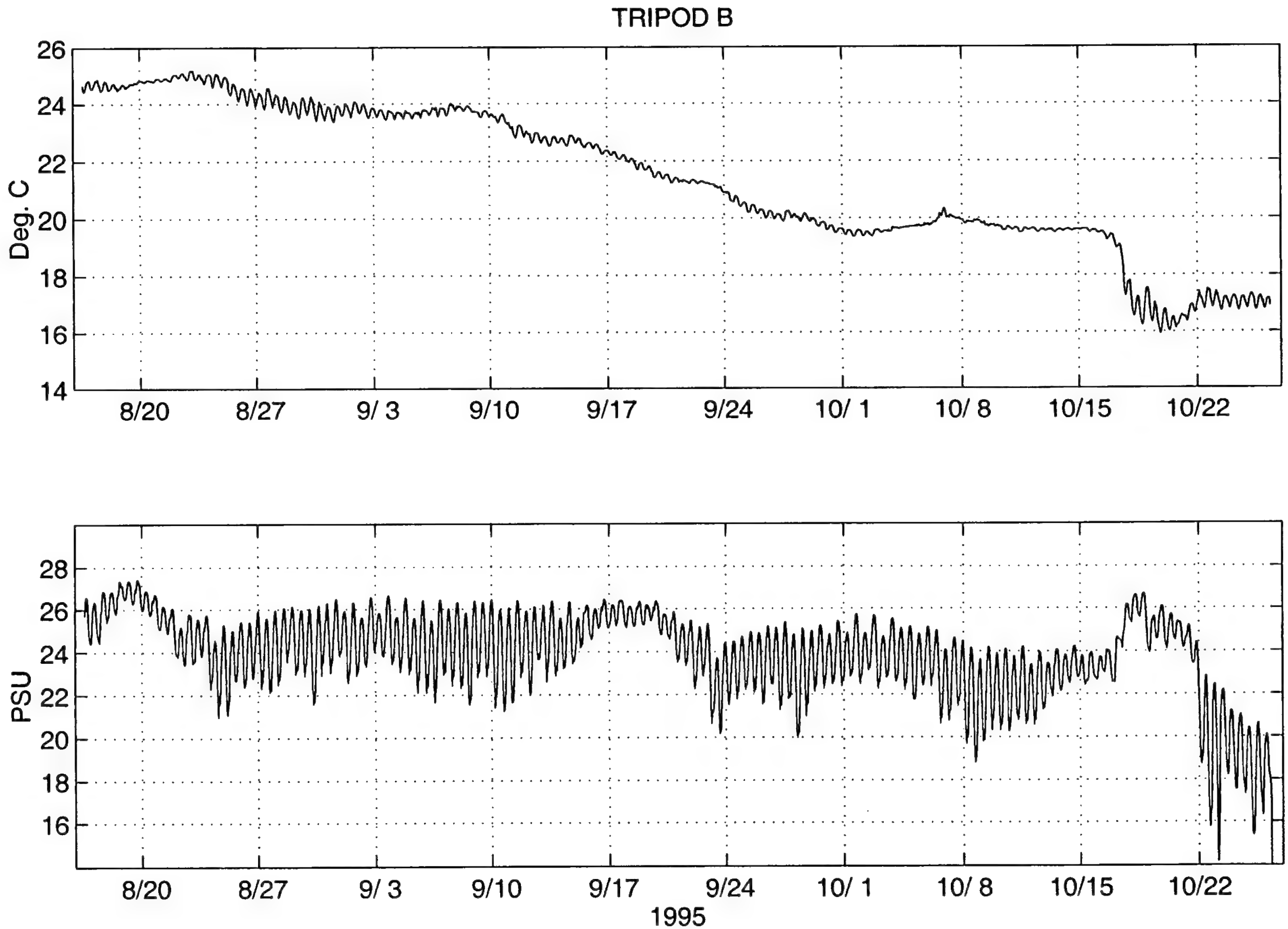


Figure 15. Tripod B: Temperature & Salinity

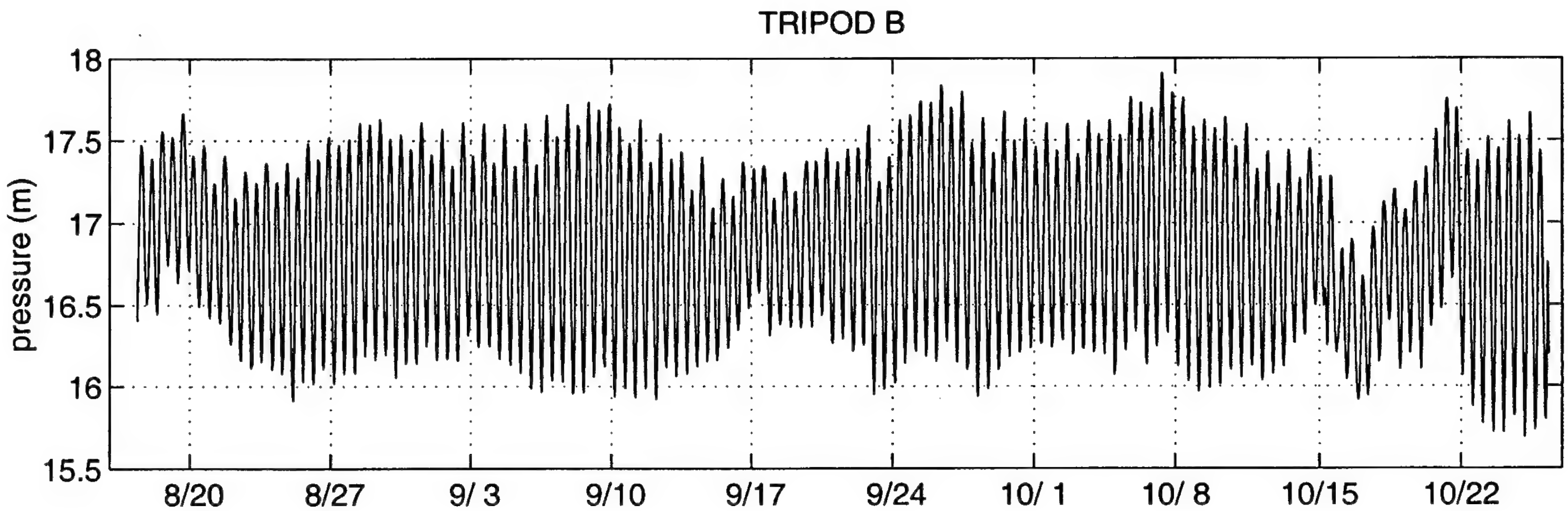


Figure 16. Tripod B: Pressure

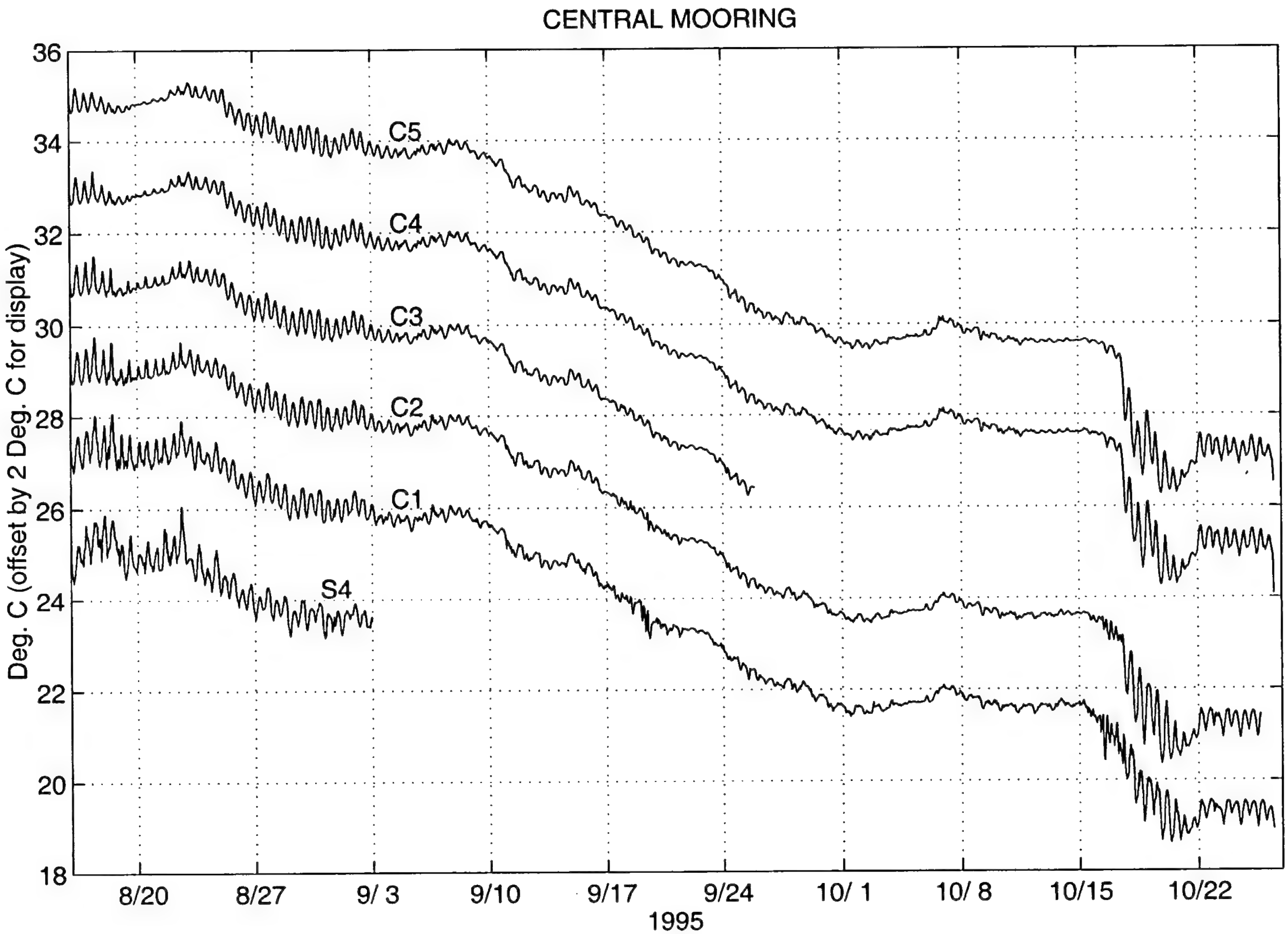


Figure 17. Central Mooring: Temperature

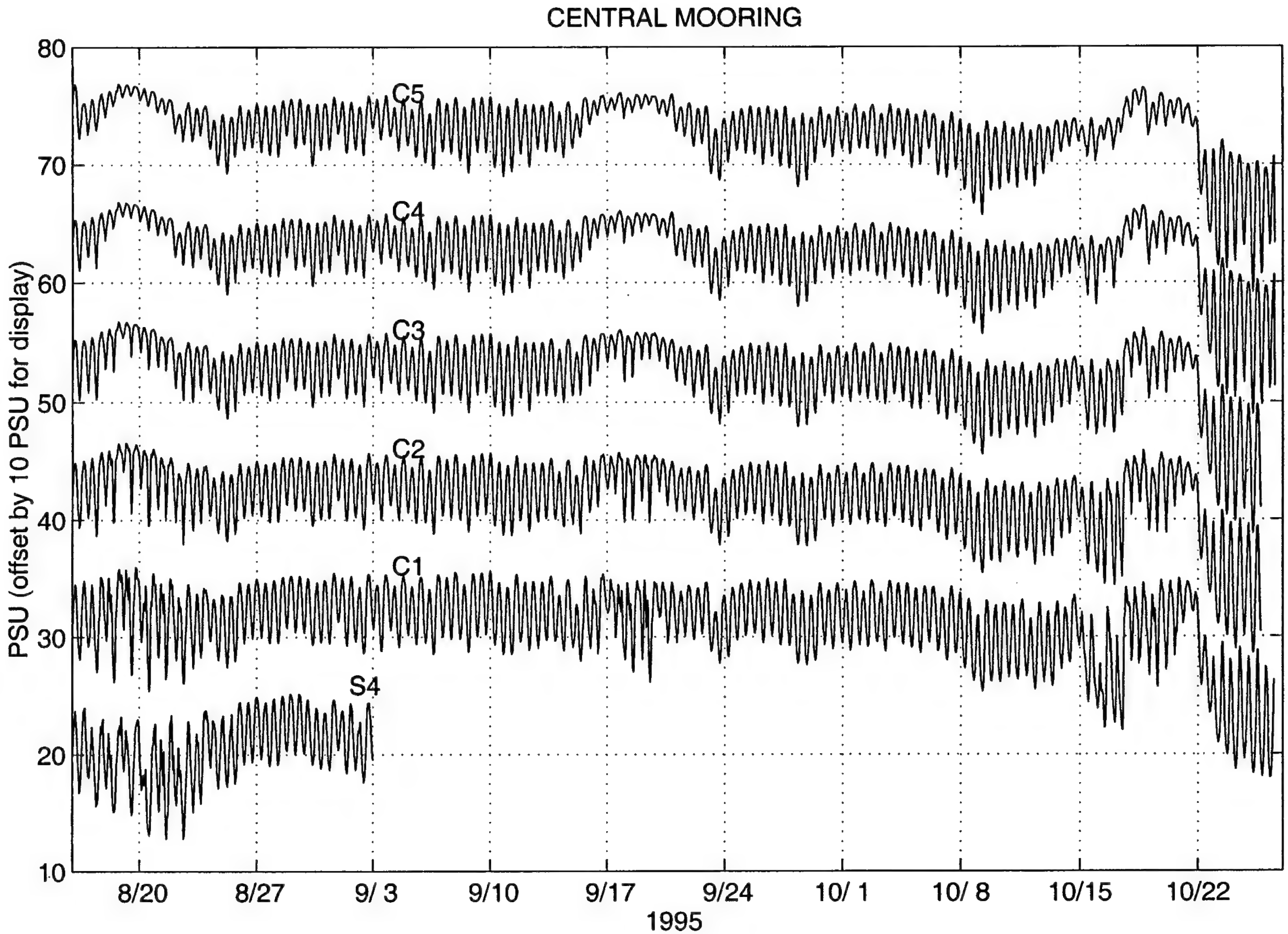


Figure 18. Central Mooring: Salinity

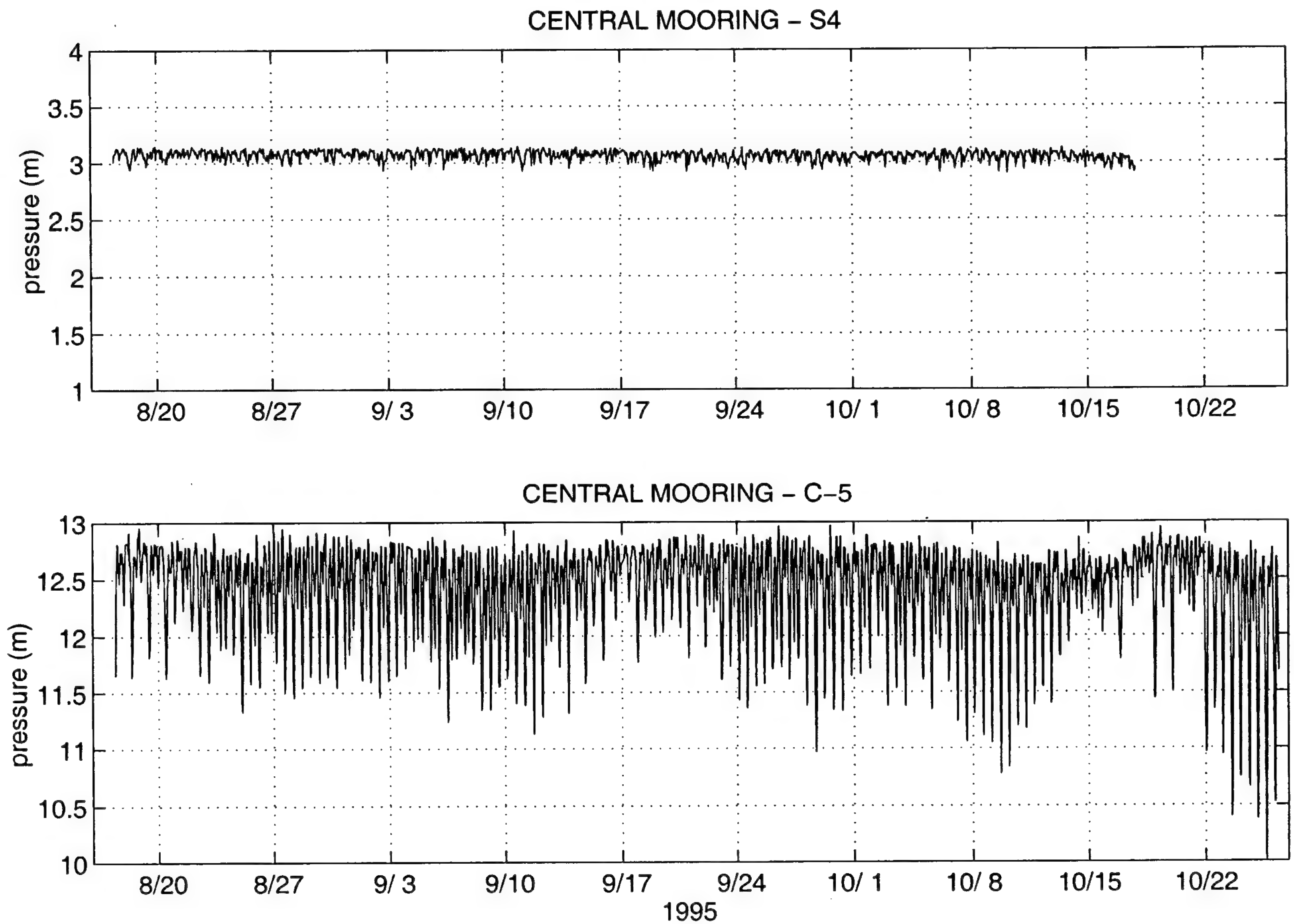


Figure 19. Central Mooring: Pressure

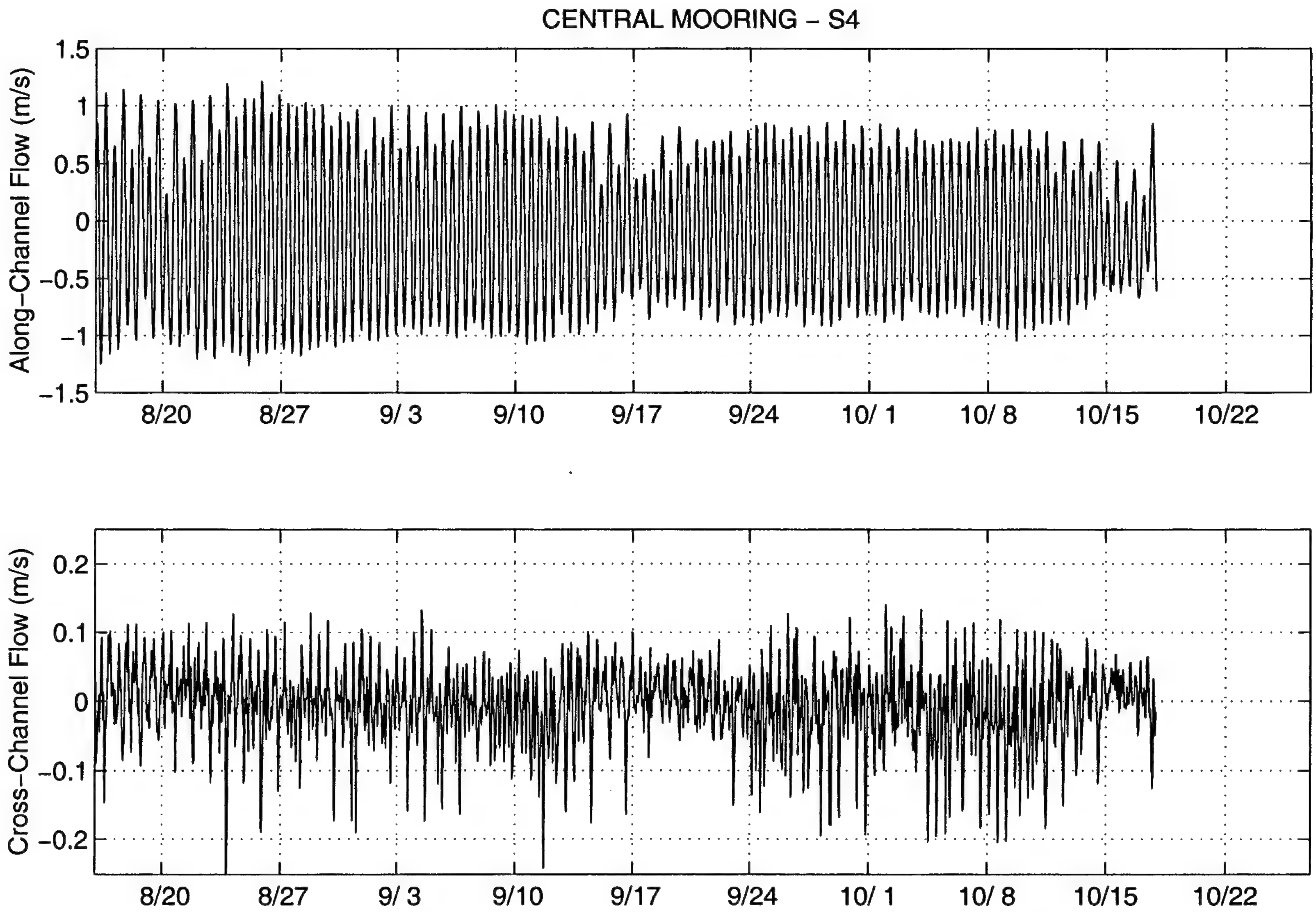


Figure 20. Central Mooring: Horizontal Velocity

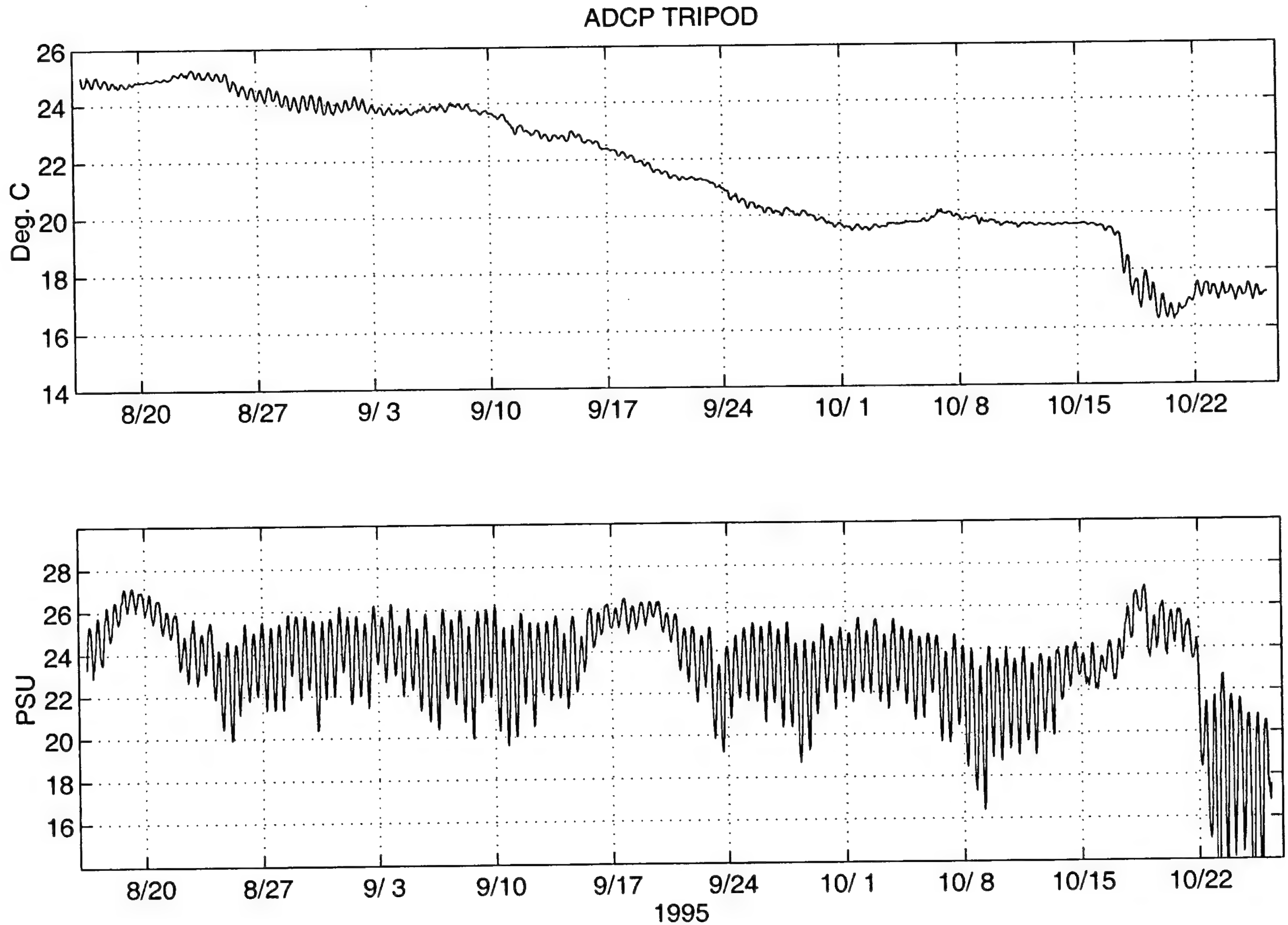


Figure 21. ADCP Tripod: Temperature & Salinity

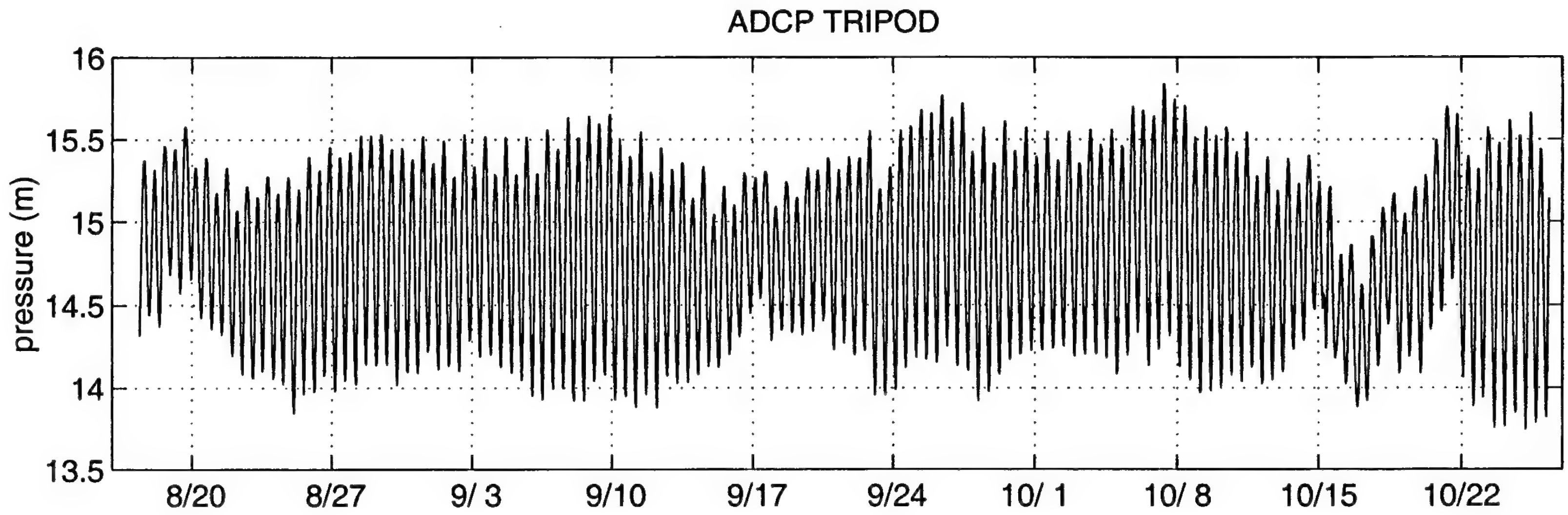


Figure 22. ADCP Tripod: Pressure

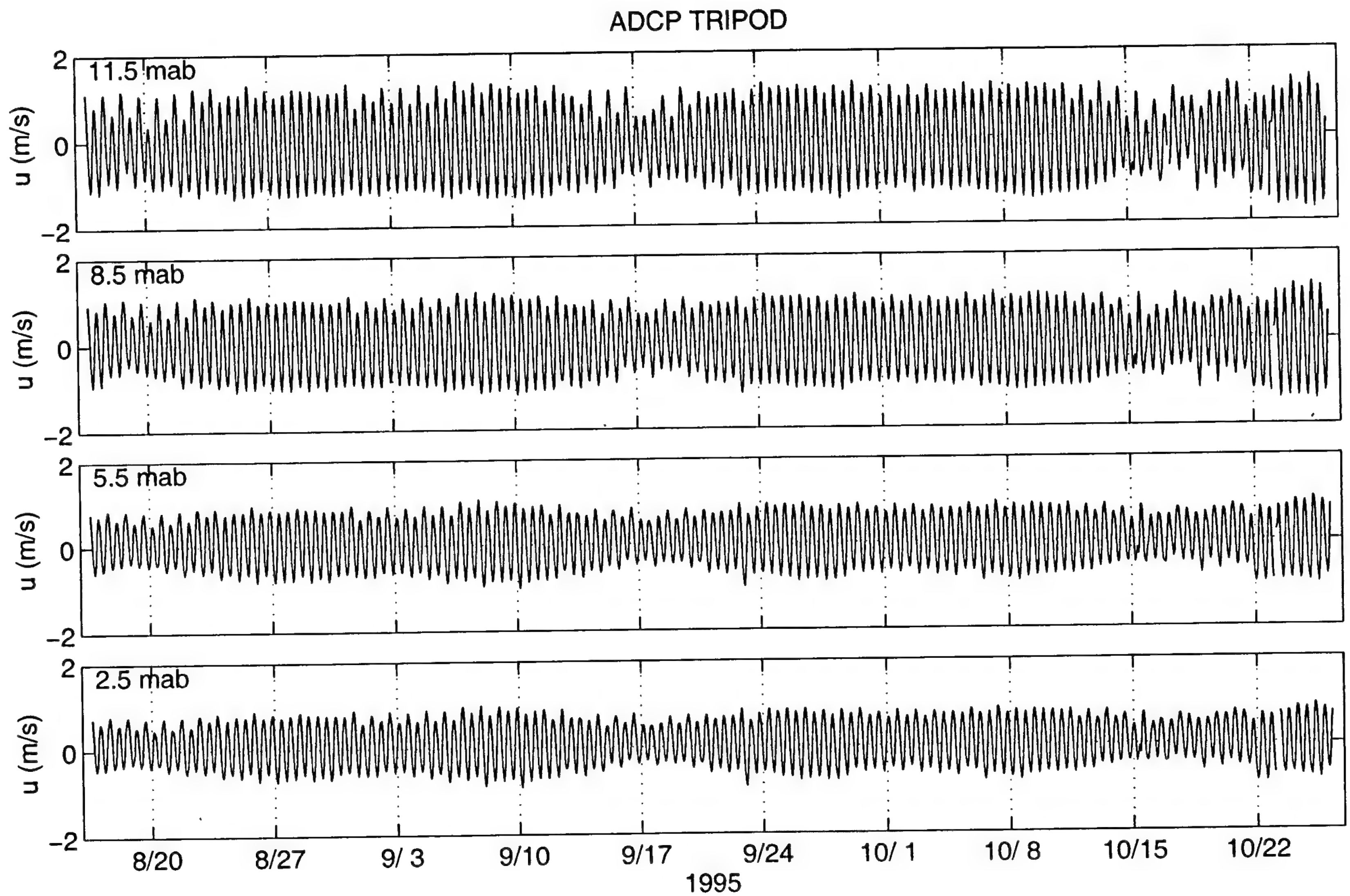


Figure 23. ADCP Tripod: Along-Channel Velocity (2.5, 5.5, 8.5 and 11.5 meters above bottom)

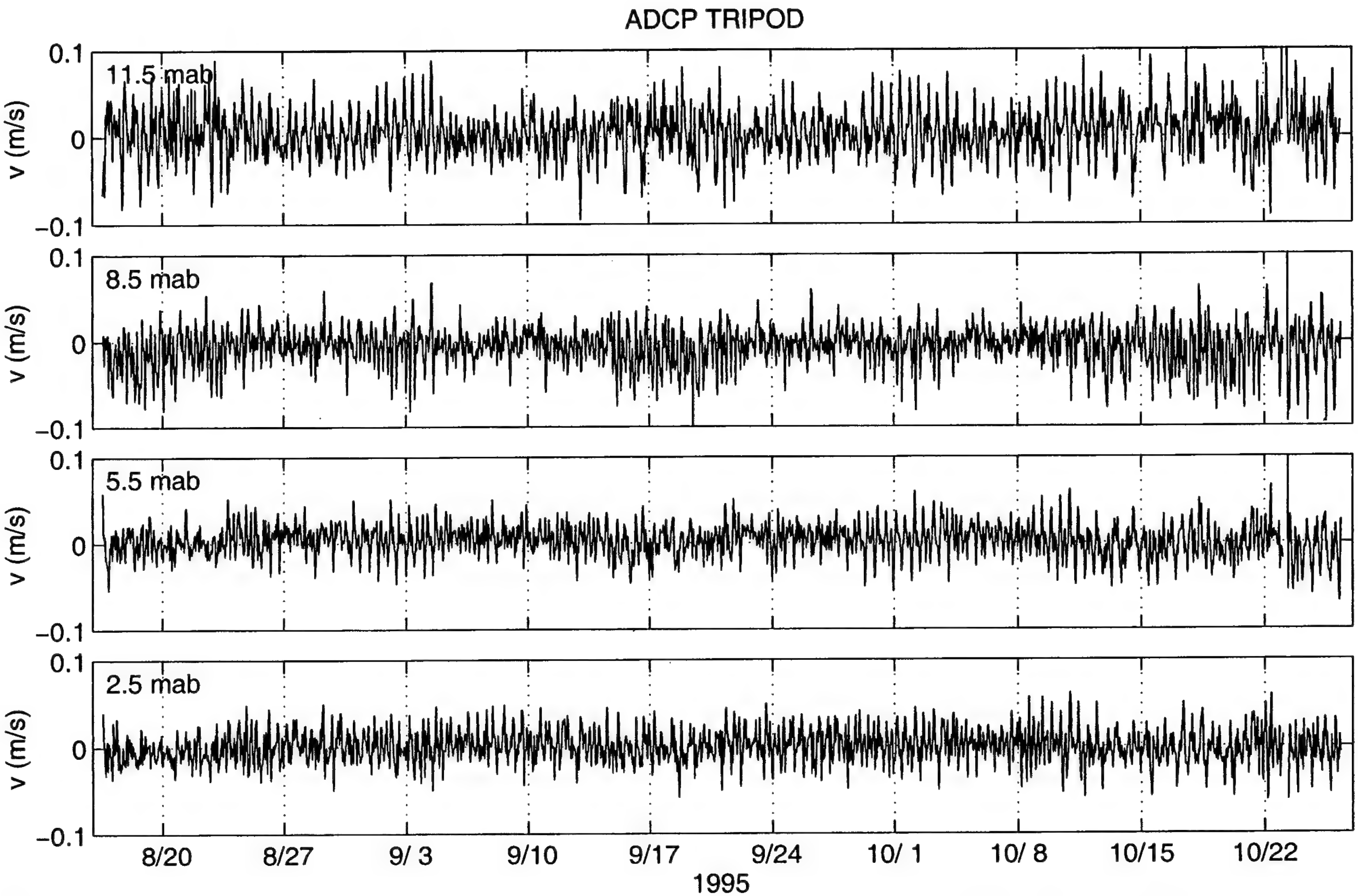


Figure 24. ADCP Tripod: Cross-Channel Velocity (2.5, 5.5, 8.5 and 11.5 meters above bottom)

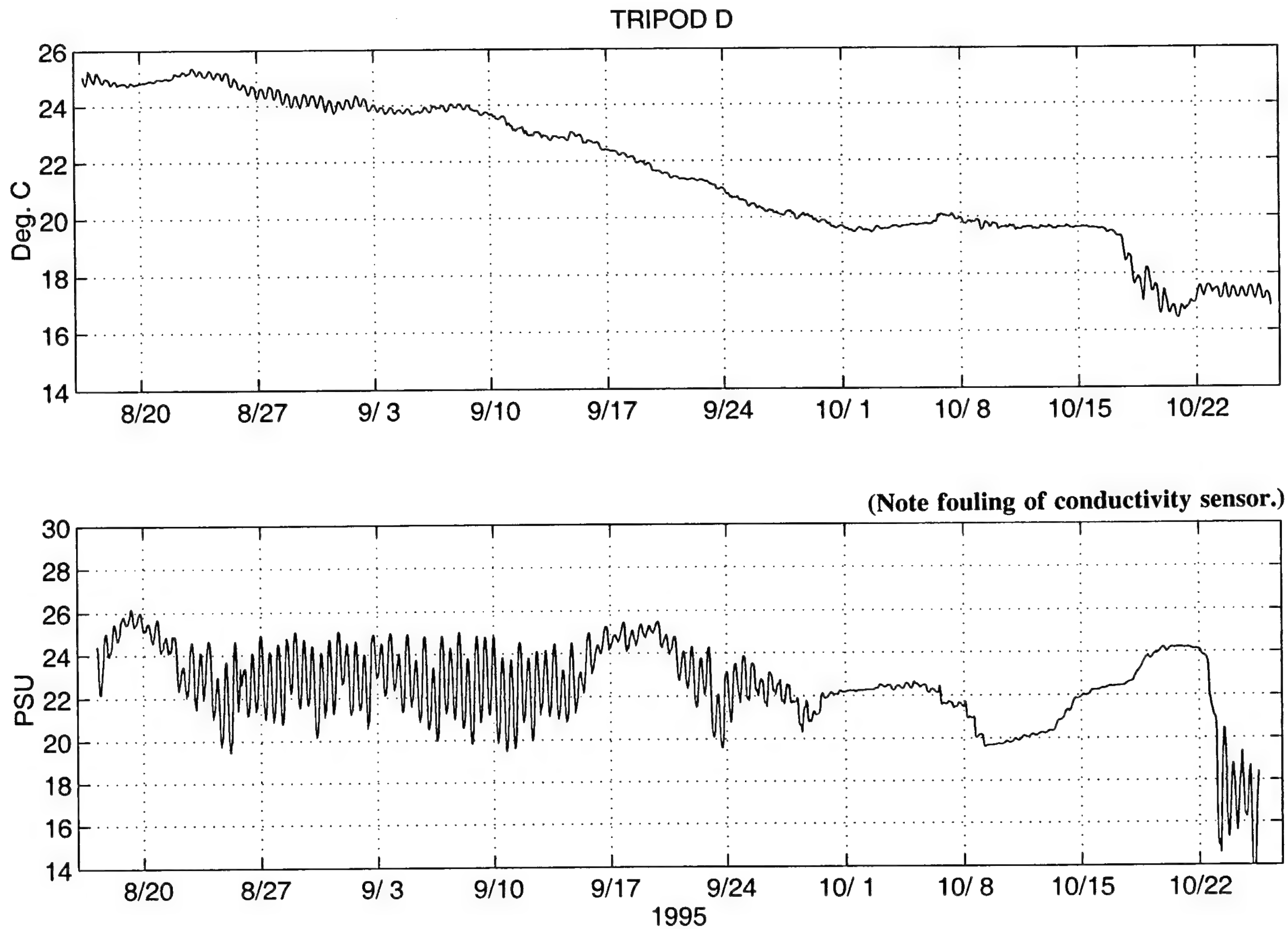


Figure 25. Tripod D: Temperature & Salinity

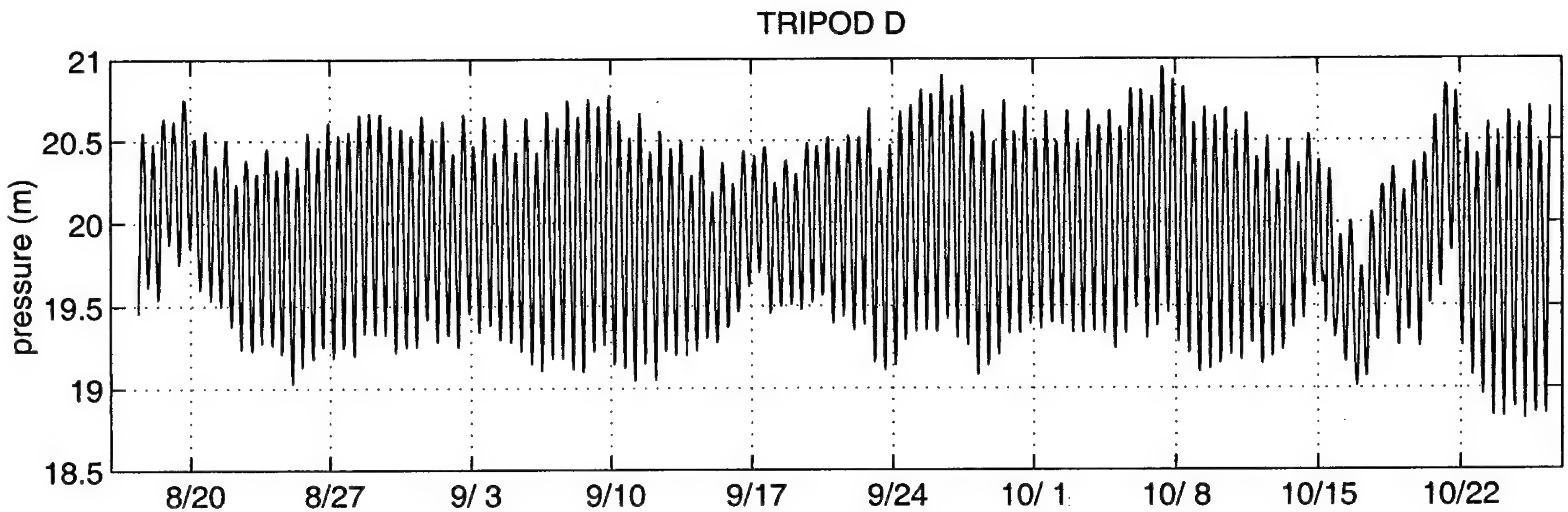


Figure 26. Tripod D: Pressure

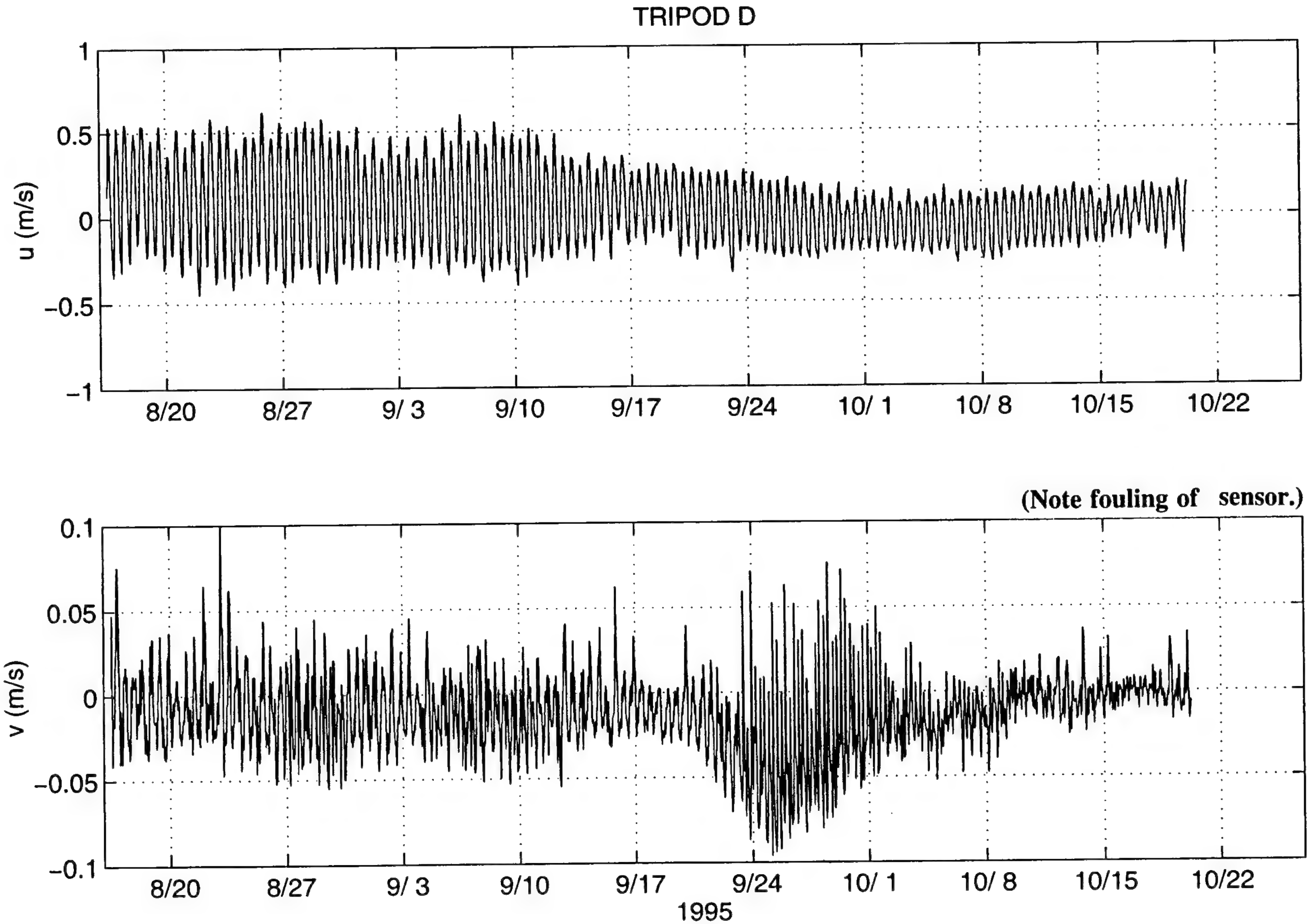


Figure 27. Tripod D: Horizontal Velocity

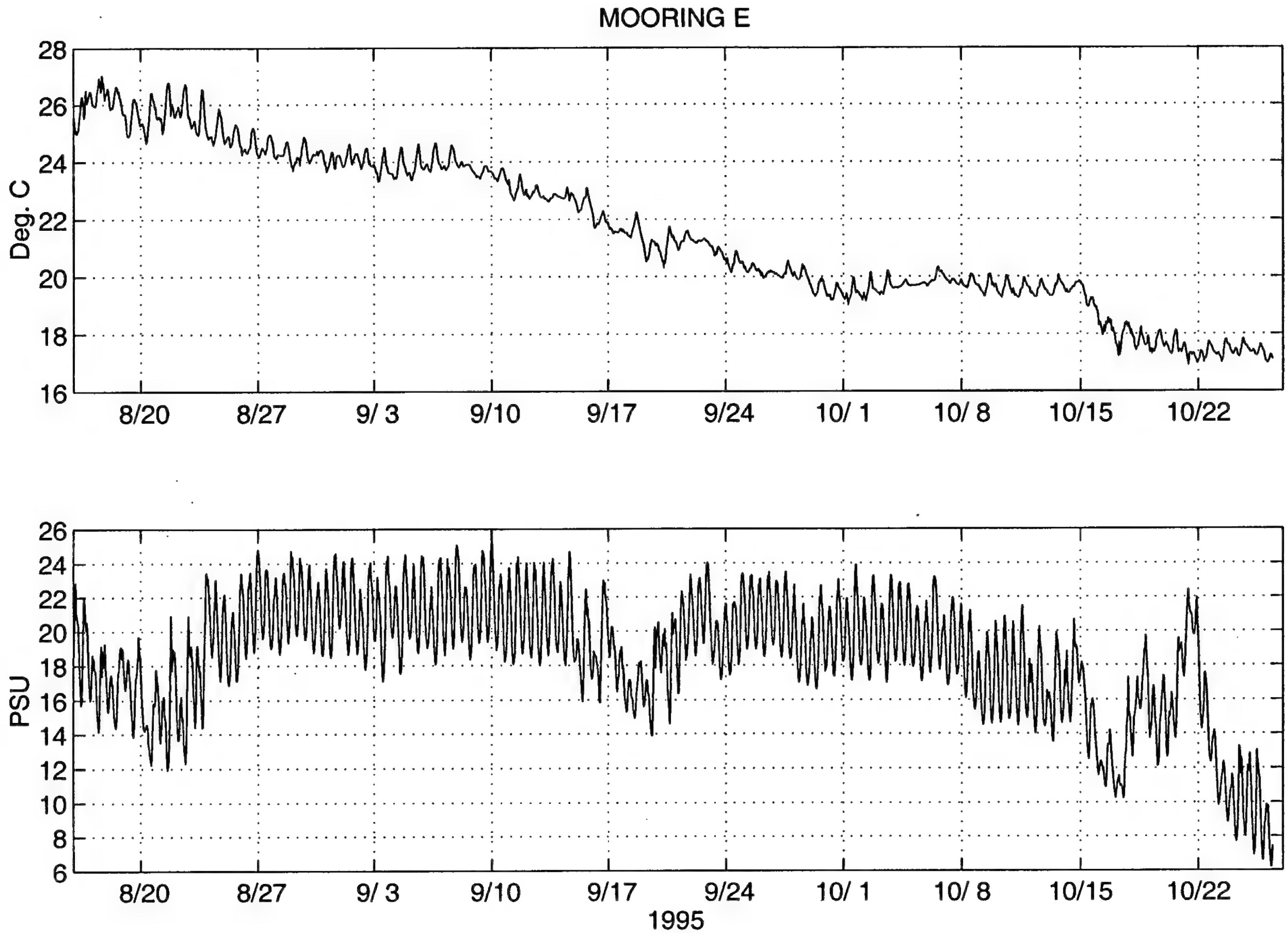


Figure 28. Mooring E: Temperature & Salinity

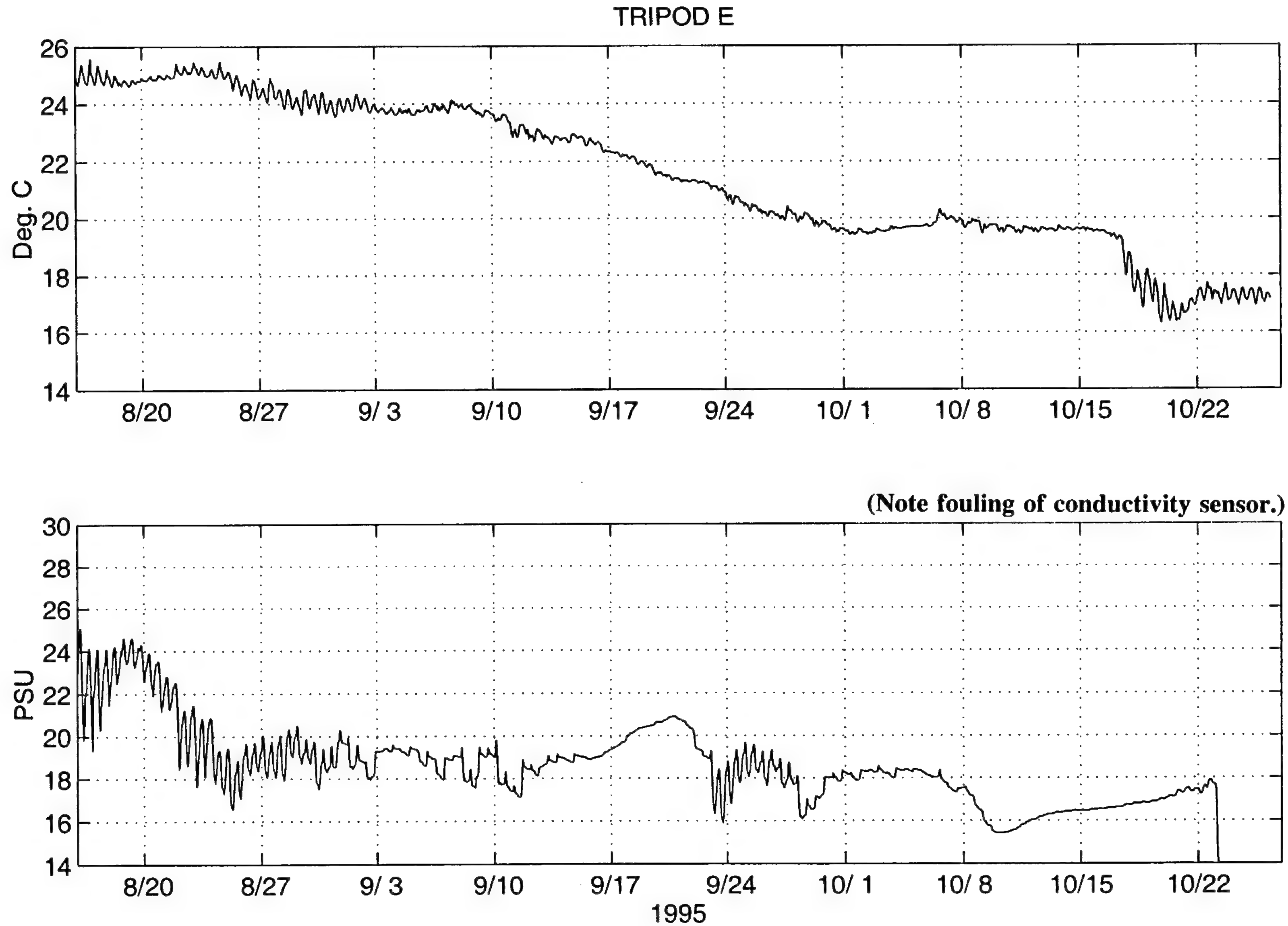


Figure 29. Tripod E: Temperature & Salinity

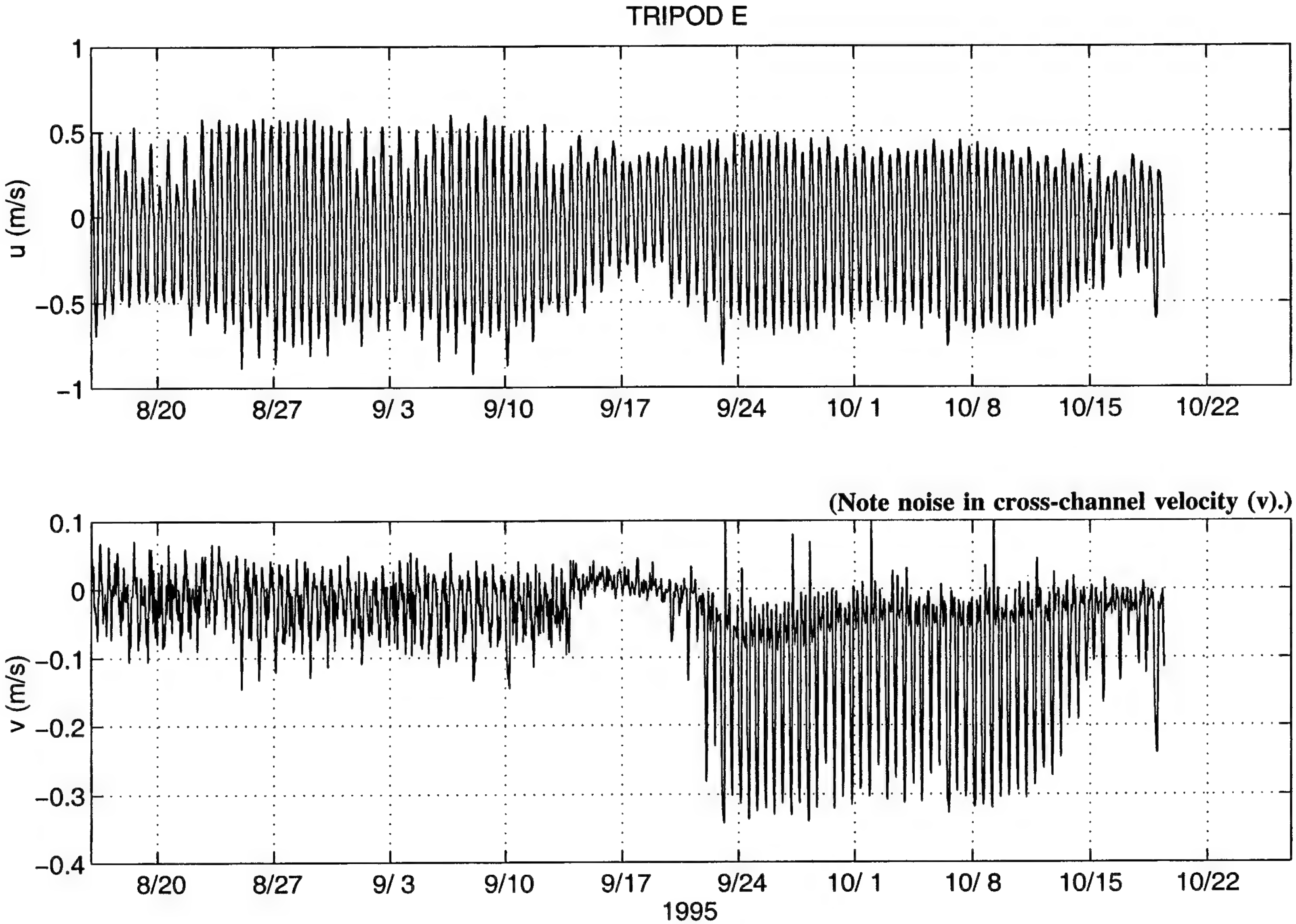


Figure 30. Tripod E: Horizontal Velocity

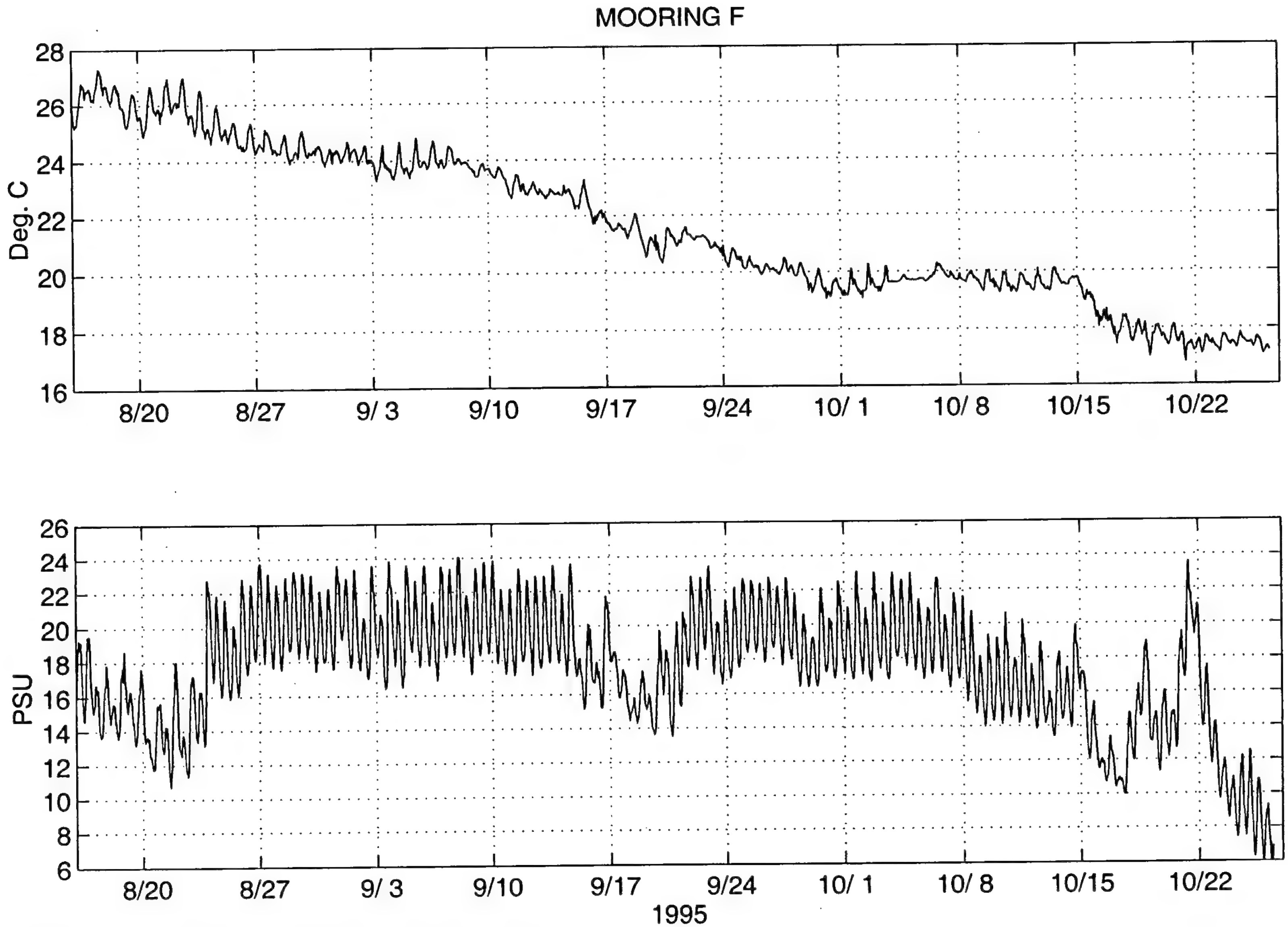


Figure 31. Mooring F: Temperature & Salinity

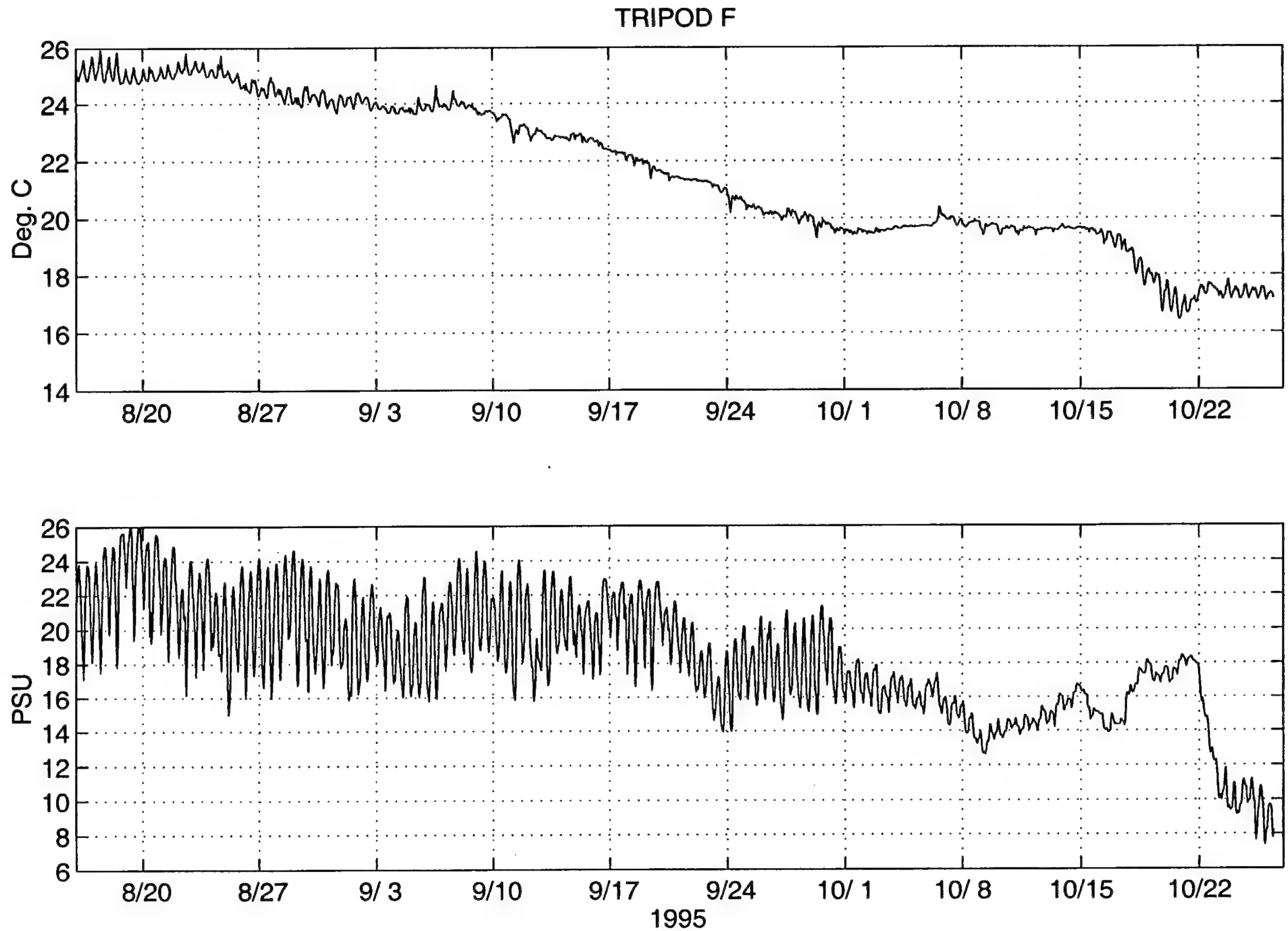


Figure 32. Tripod F: Temperature & Salinity

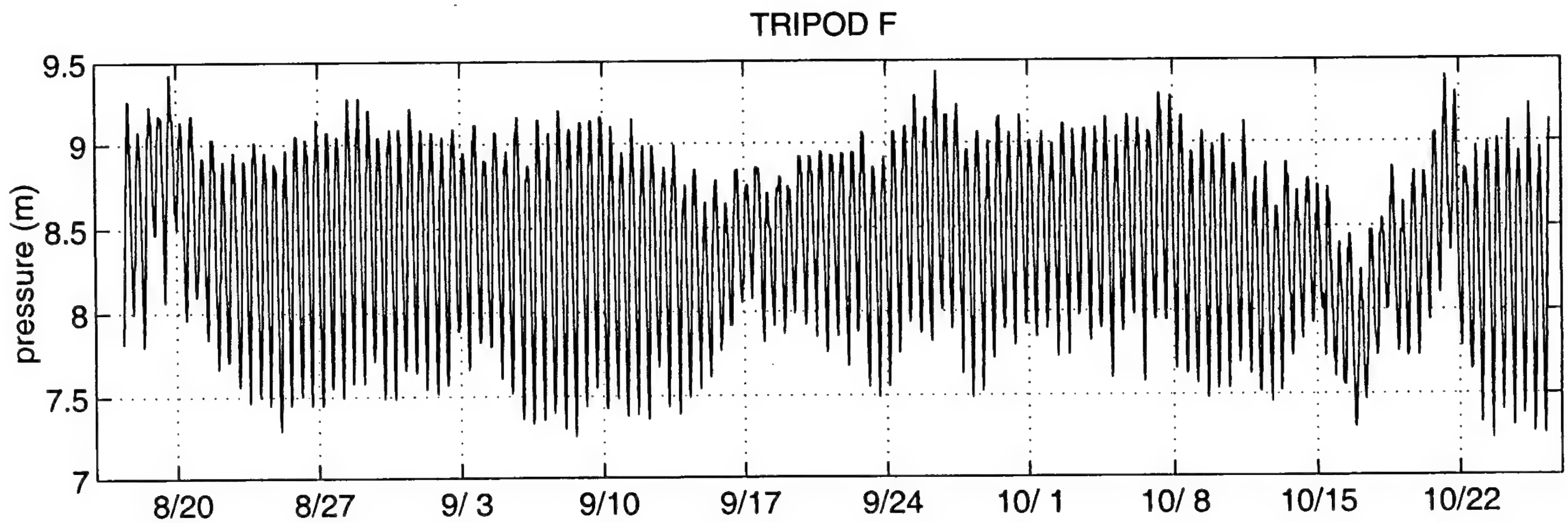


Figure 33. Tripod F: Pressure

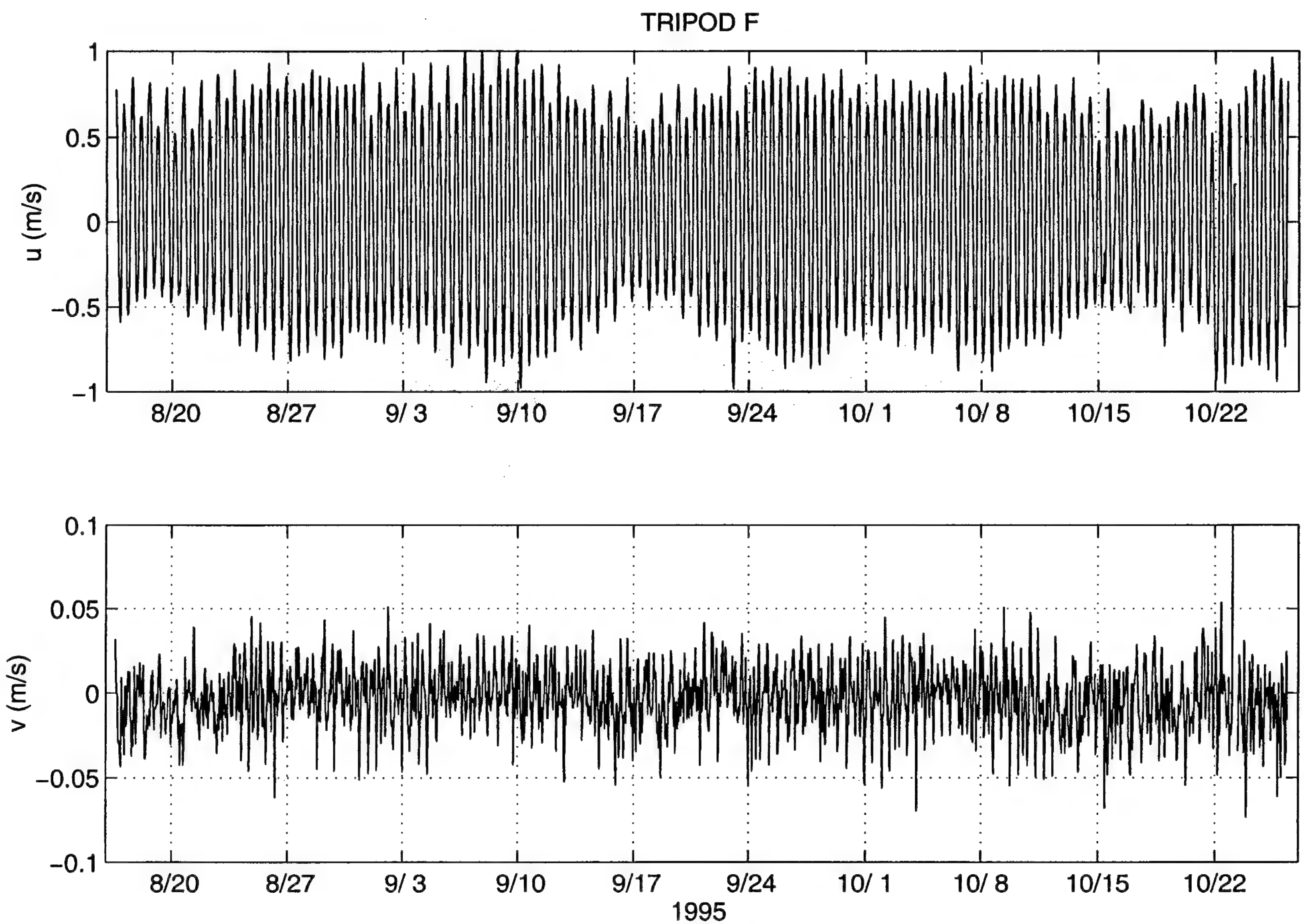
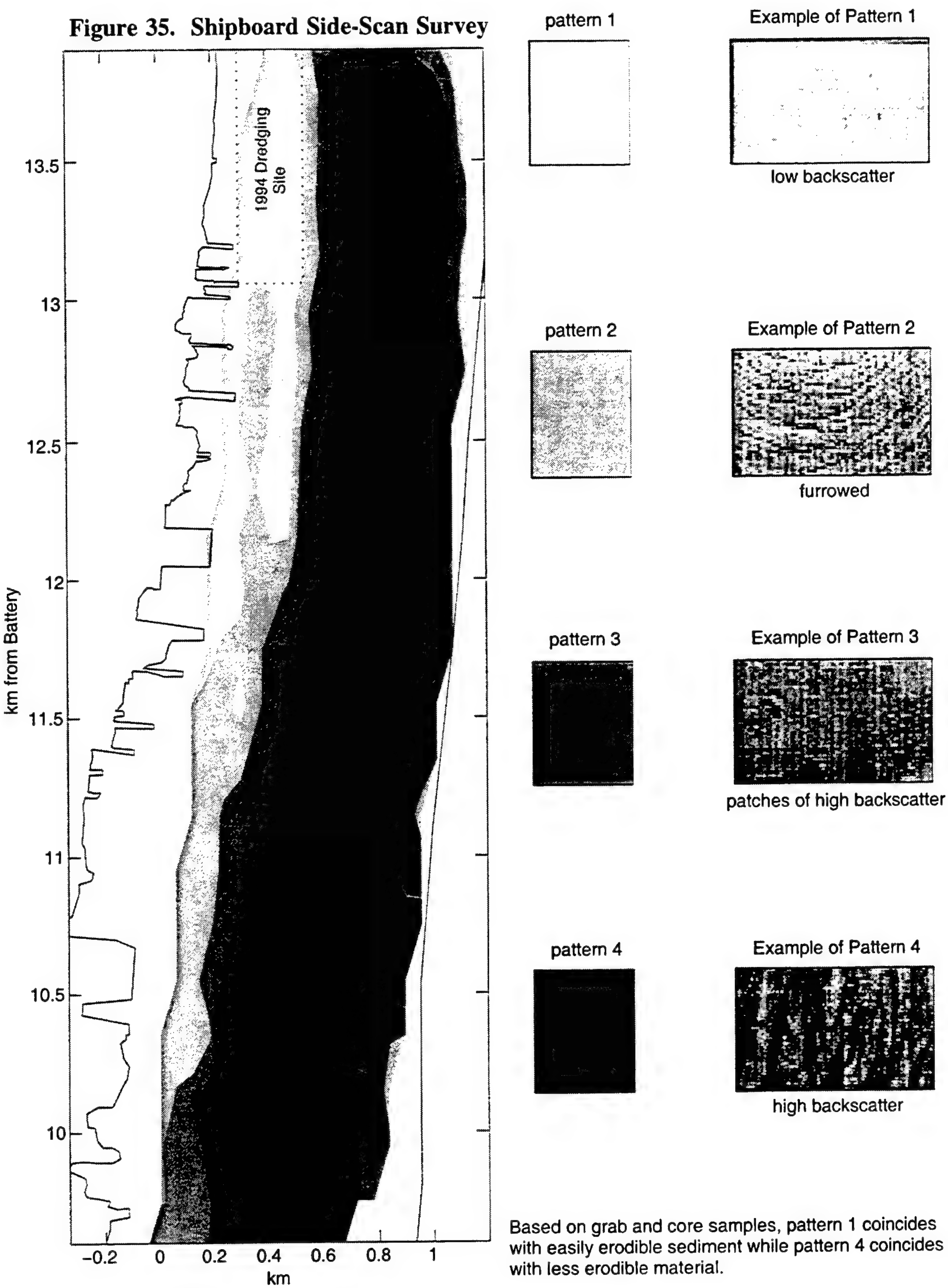


Figure 34. Tripod F: Horizontal Velocity

Figure 35. Shipboard Side-Scan Survey



Based on grab and core samples, pattern 1 coincides with easily erodible sediment while pattern 4 coincides with less erodible material.

D. SHIPBOARD DATA

Side-scan sonar results are summarized in figure 35.

Salinity and temperature contours of the longitudinal surveys are presented in figures 36 - 40. The mean hourly averaged velocities (mean of ADCP bins at 4.5, 6.5, 8.5, 10.5 and 11.5 meters) are included at the bottom of each page, with the patches representing the time of each survey.

Velocity and salinity contours of the transect surveys are presented in figures 41 - 55.

The mean hourly averaged velocities (as described above) are included for the days when long surveys were conducted (Figure 56). Salinity and temperature contours of the long surveys are presented in figures 57 - 60.

Figure 36a. Longitudinal Survey (8/17/95): Salinity Contour

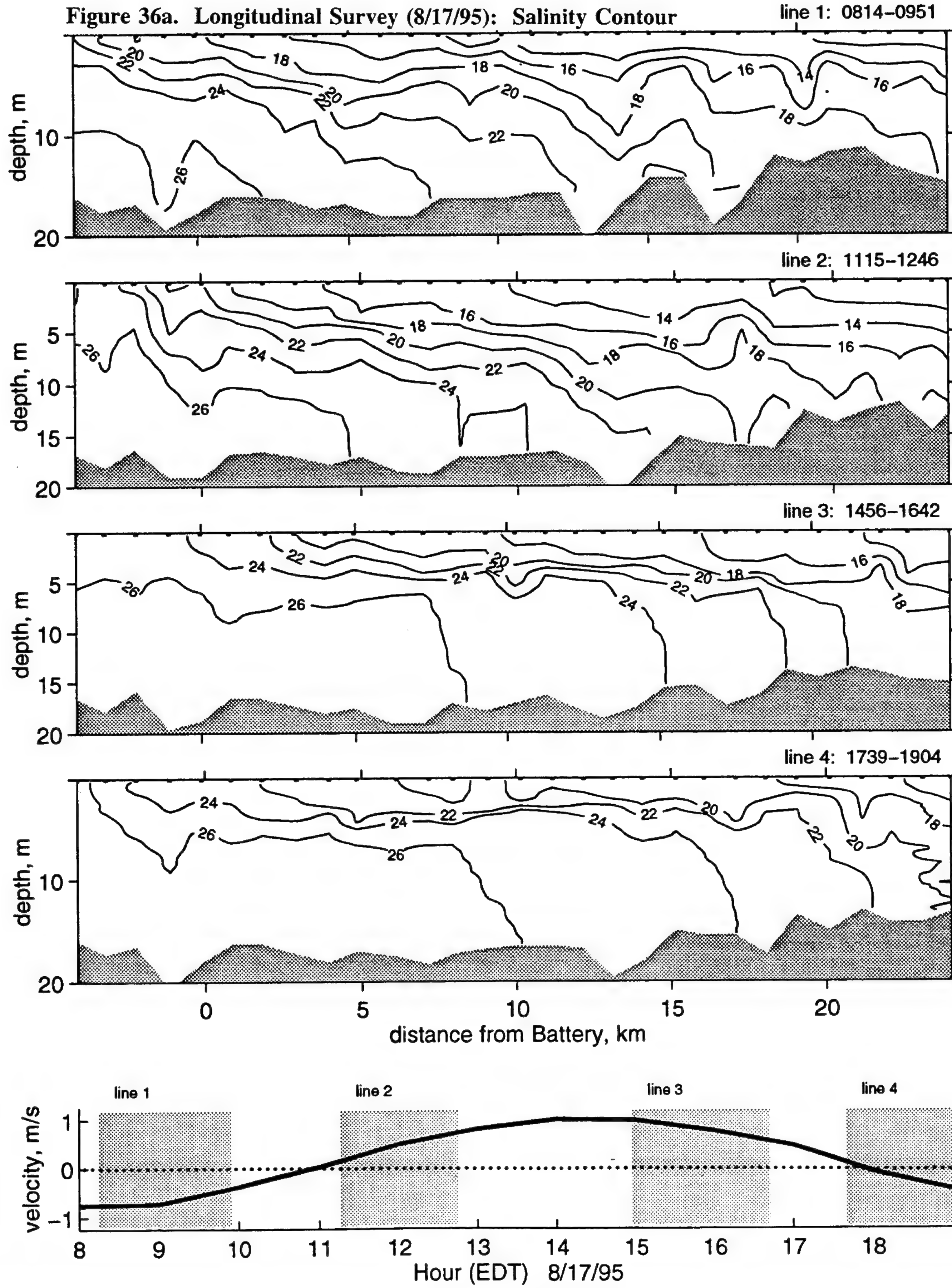


Figure 36b. Longitudinal Survey (8/17/95): Temperature Contour

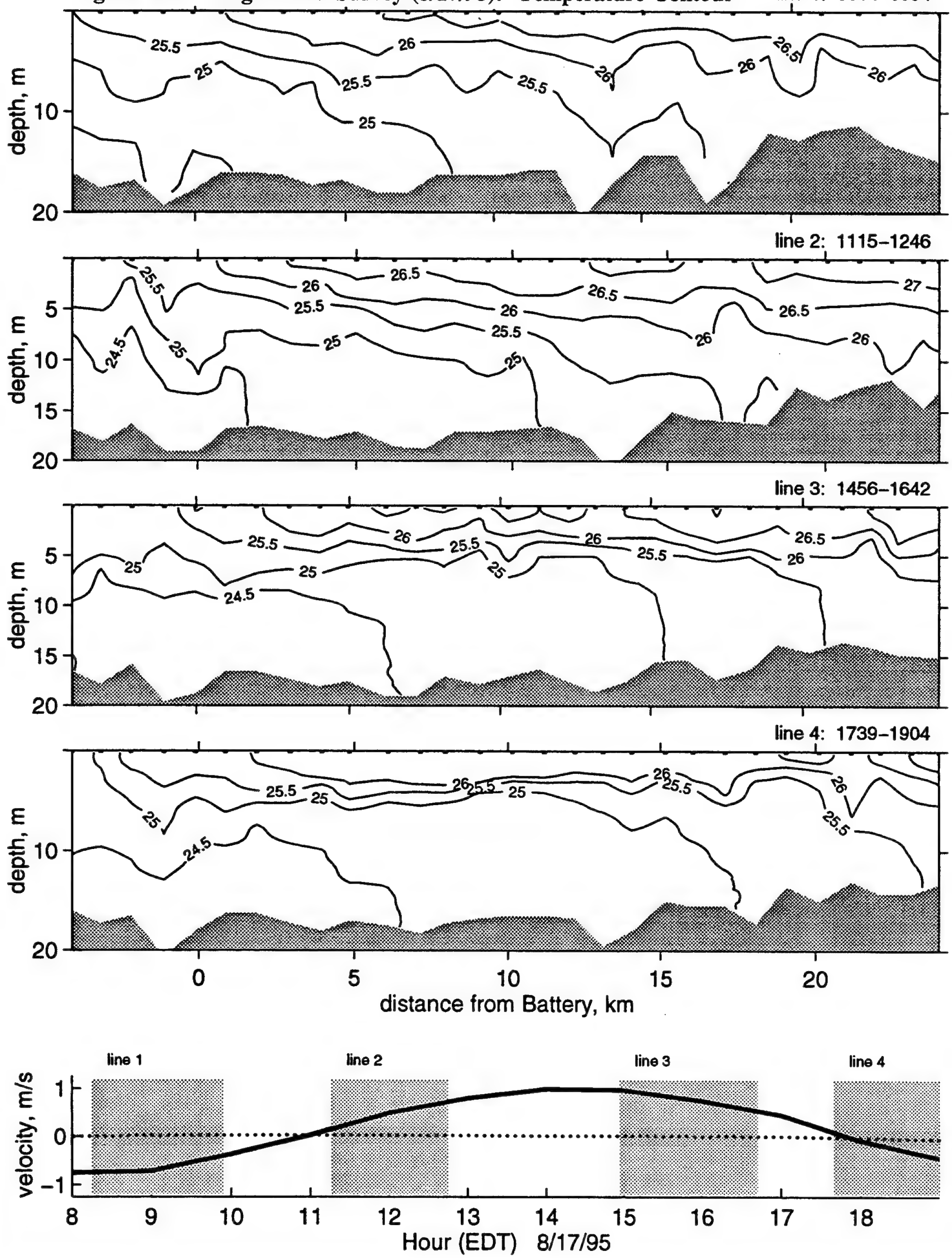


Figure 37a. Longitudinal Survey (8/27/95): Salinity Contour

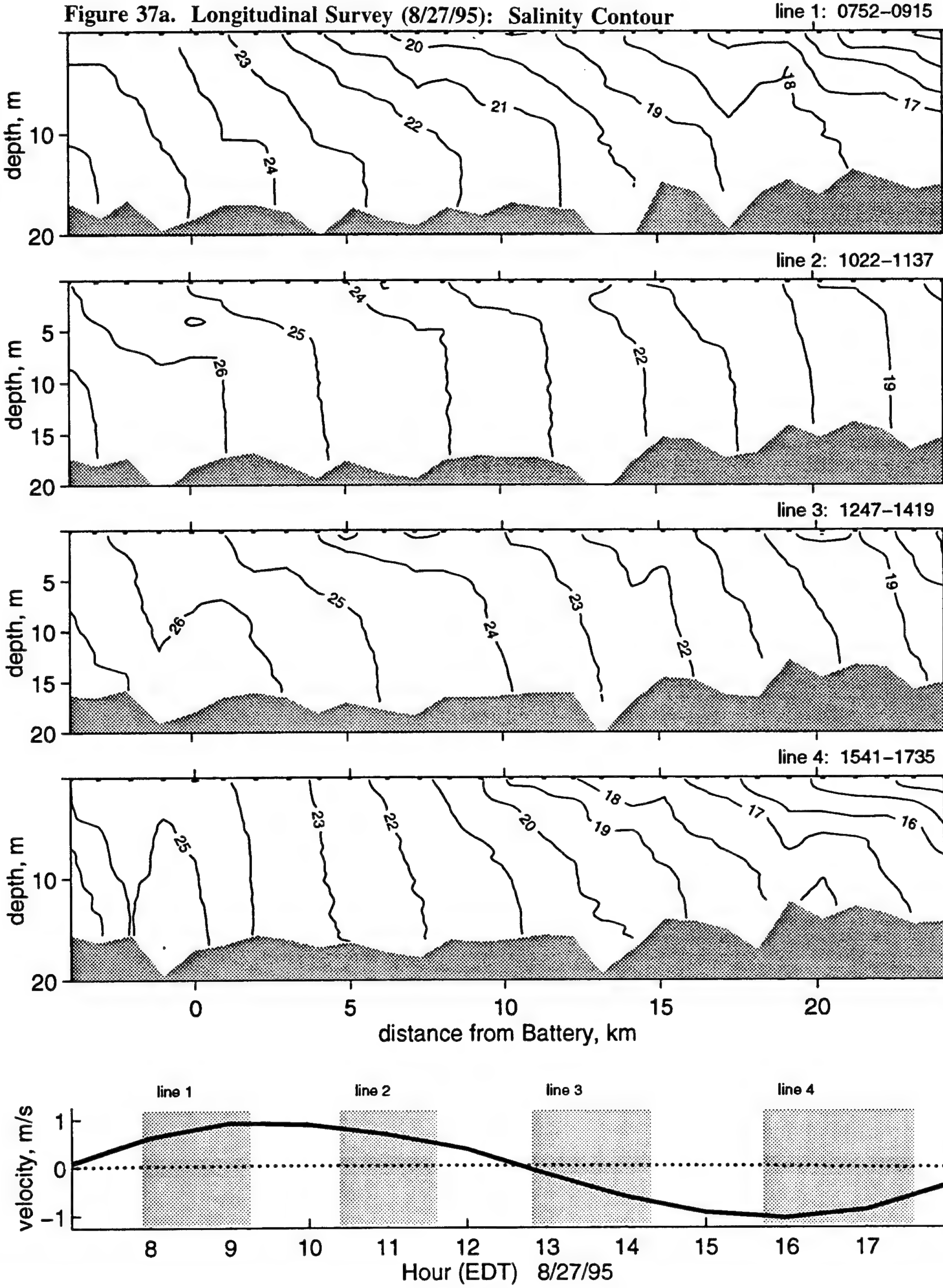


Figure 37b. Longitudinal Survey (8/27/95): Temperature Contour

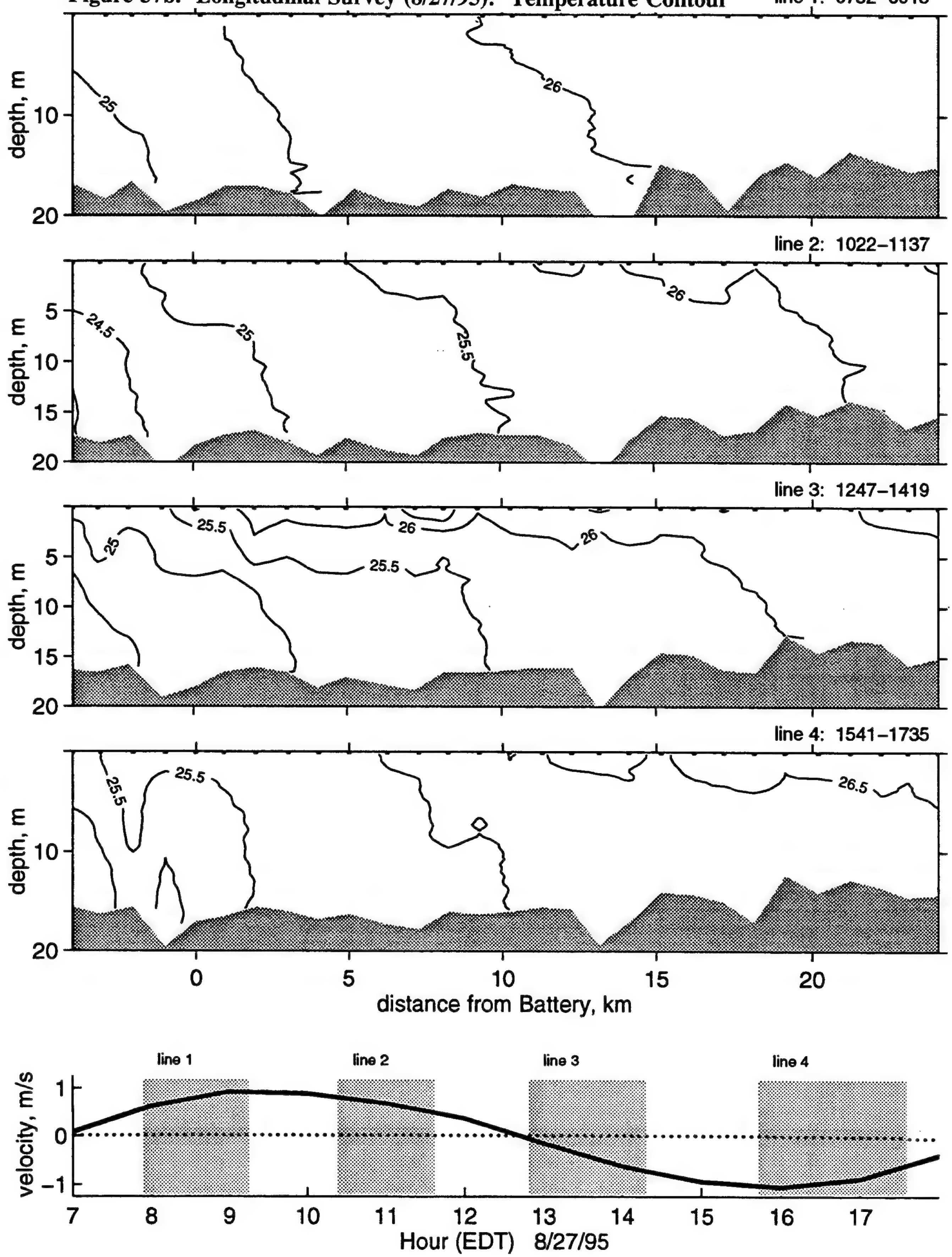


Figure 38a. Longitudinal Survey (10/18/95): Salinity Contour

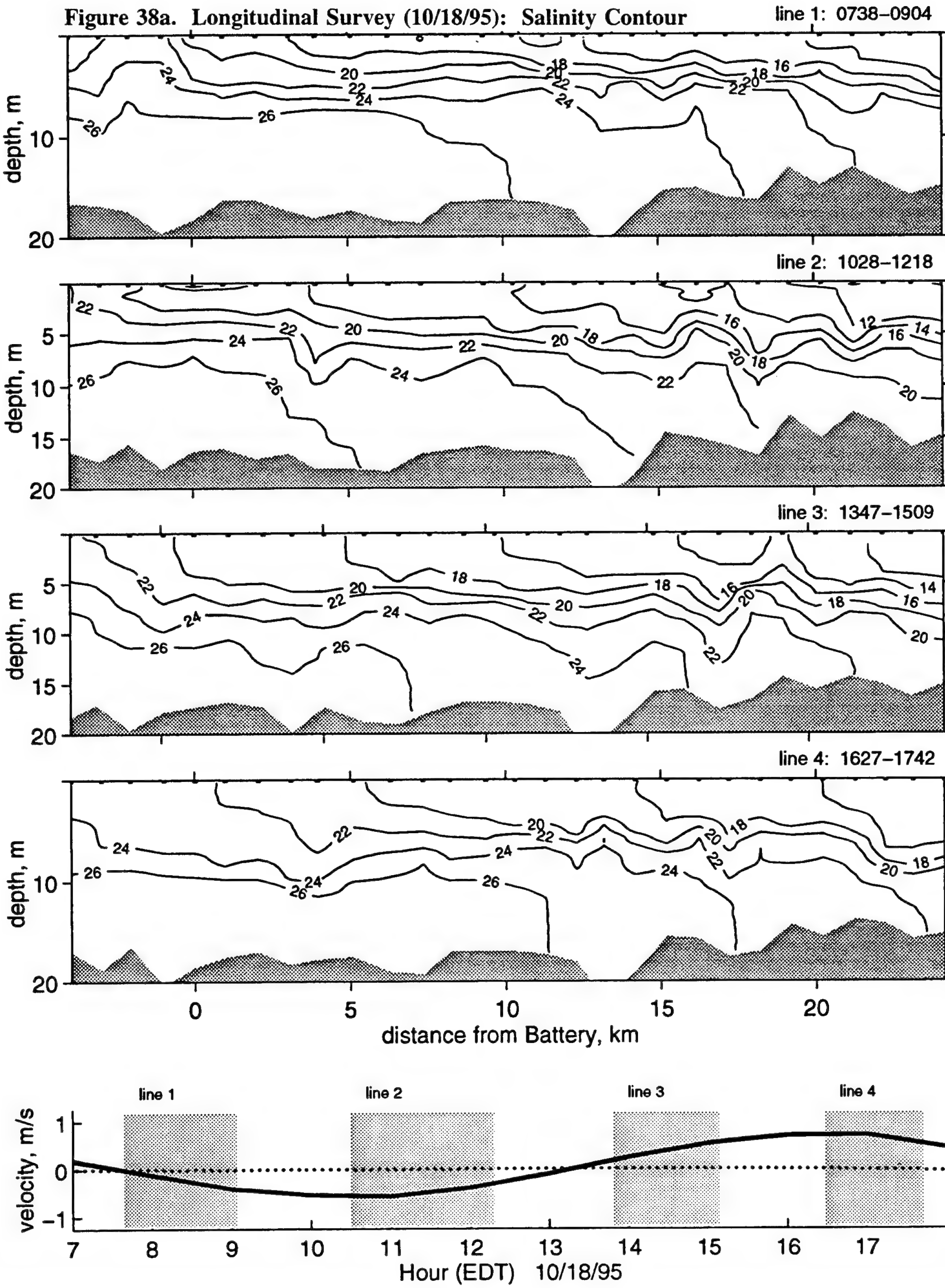


Figure 38b. Longitudinal Survey (10/18/95): Temperature Contour

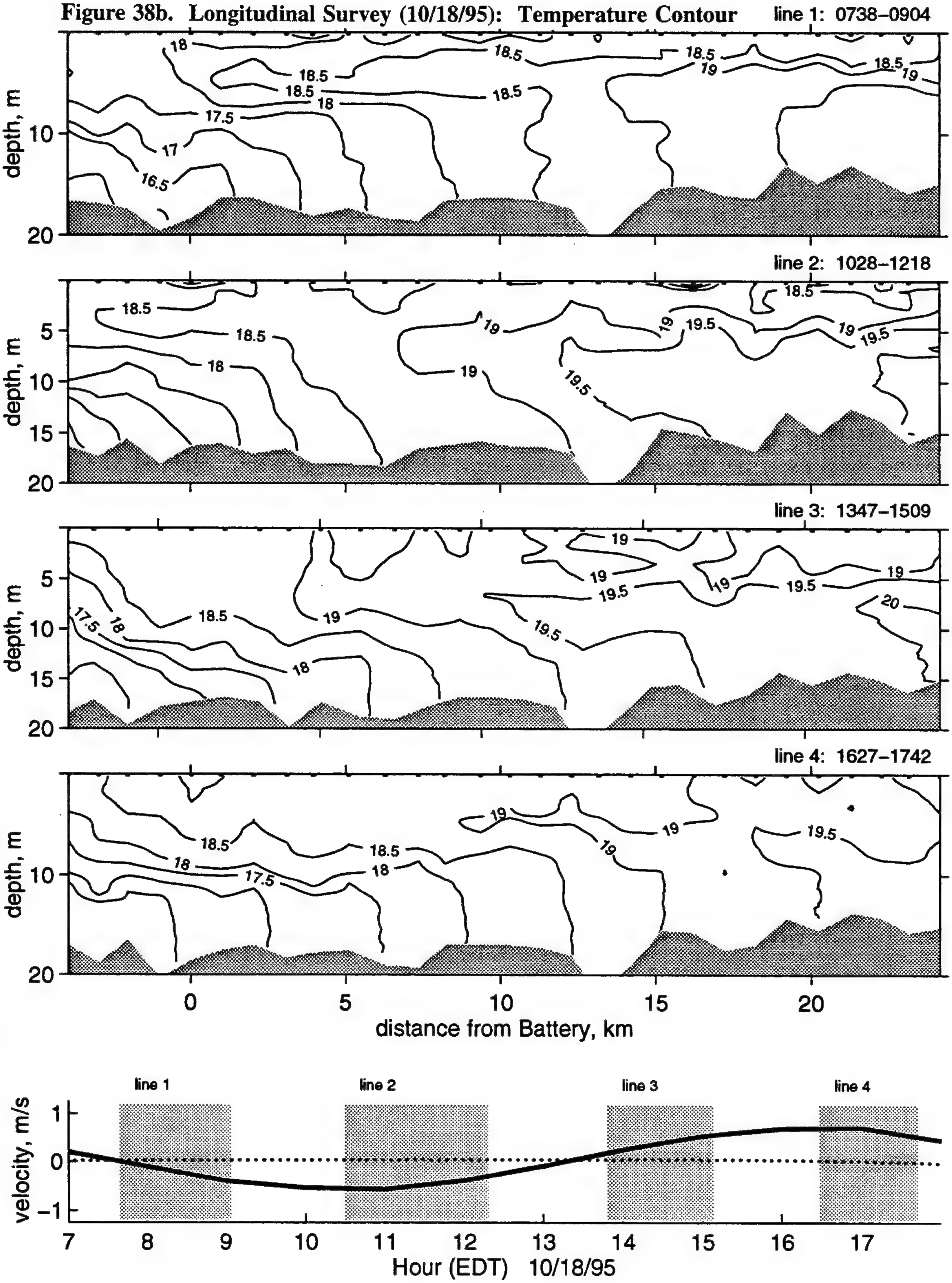


Figure 39a. Longitudinal Survey (10/20/95): Salinity Contour

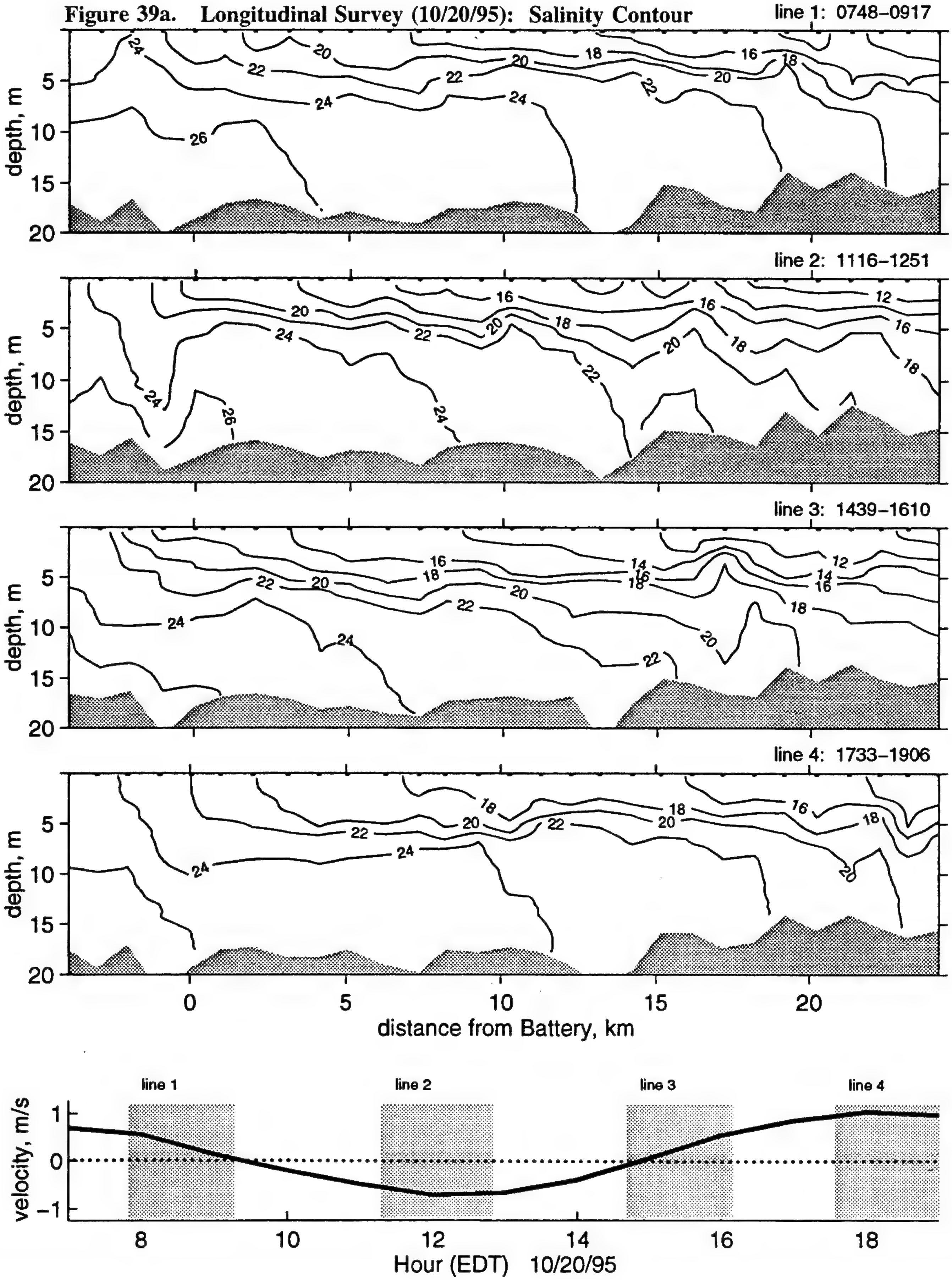


Figure 39b. Longitudinal Survey (10/20/95): Temperature Contour

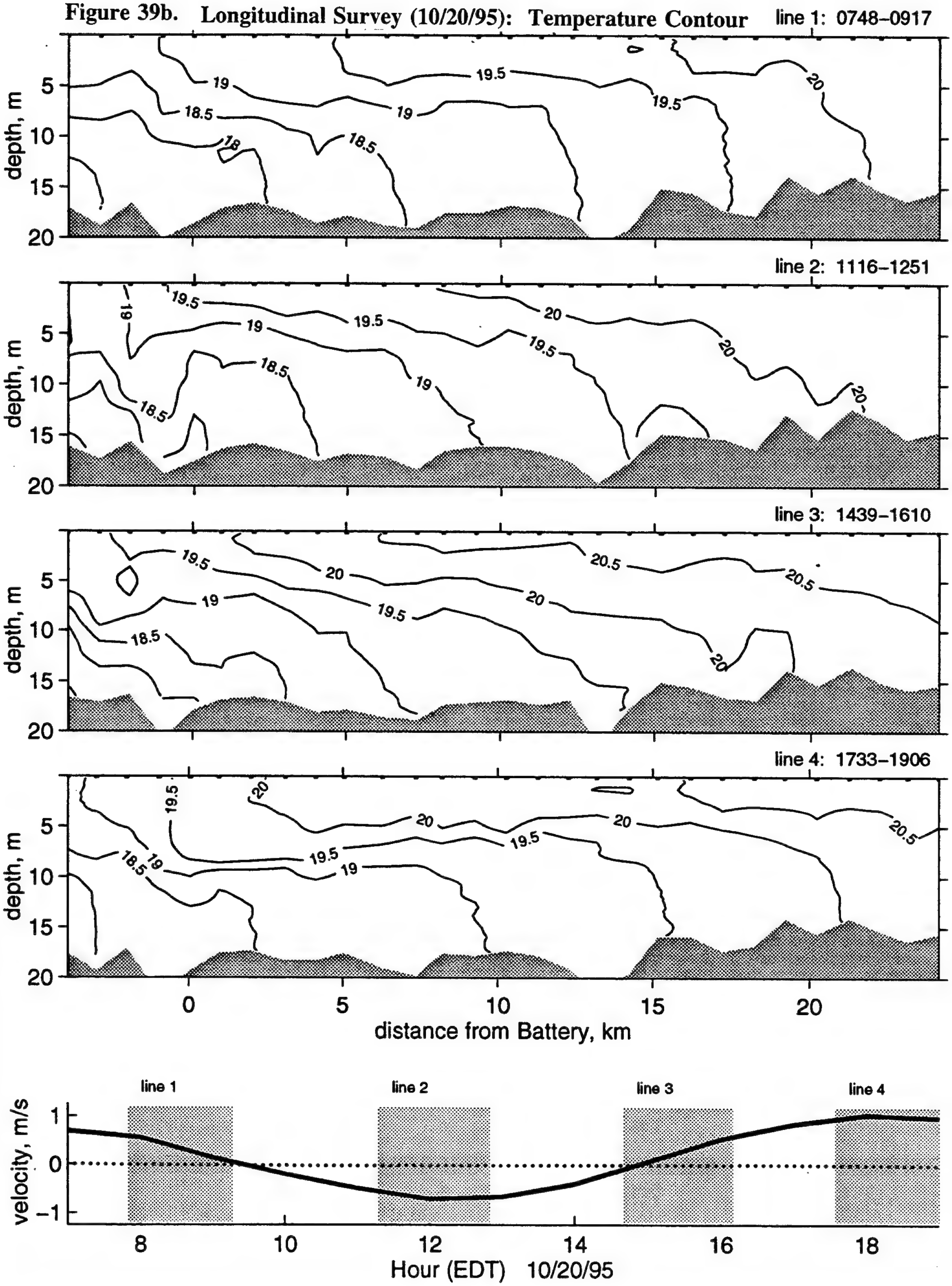


Figure 40a. Longitudinal Survey (10/22/95): Salinity Contour

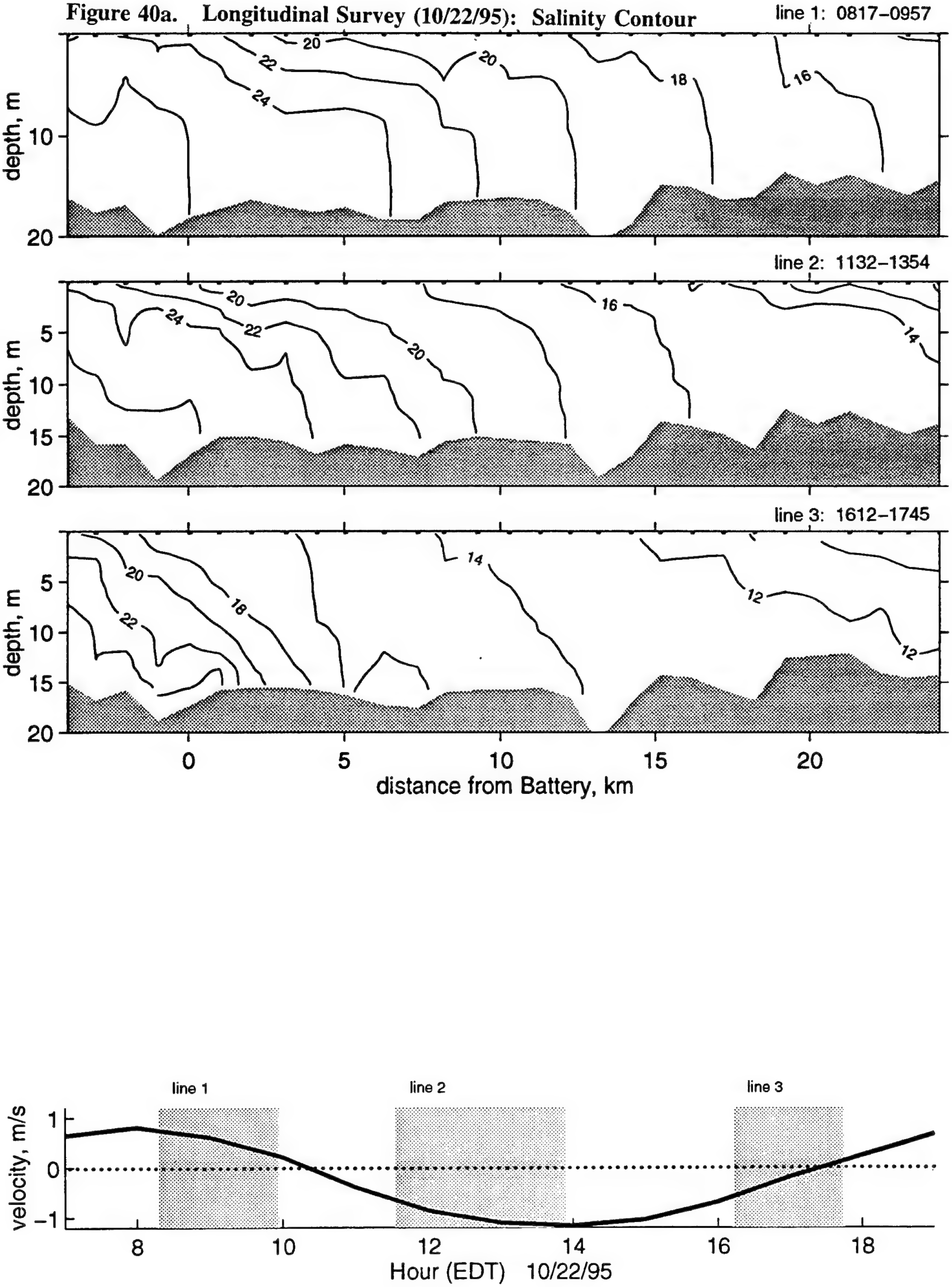
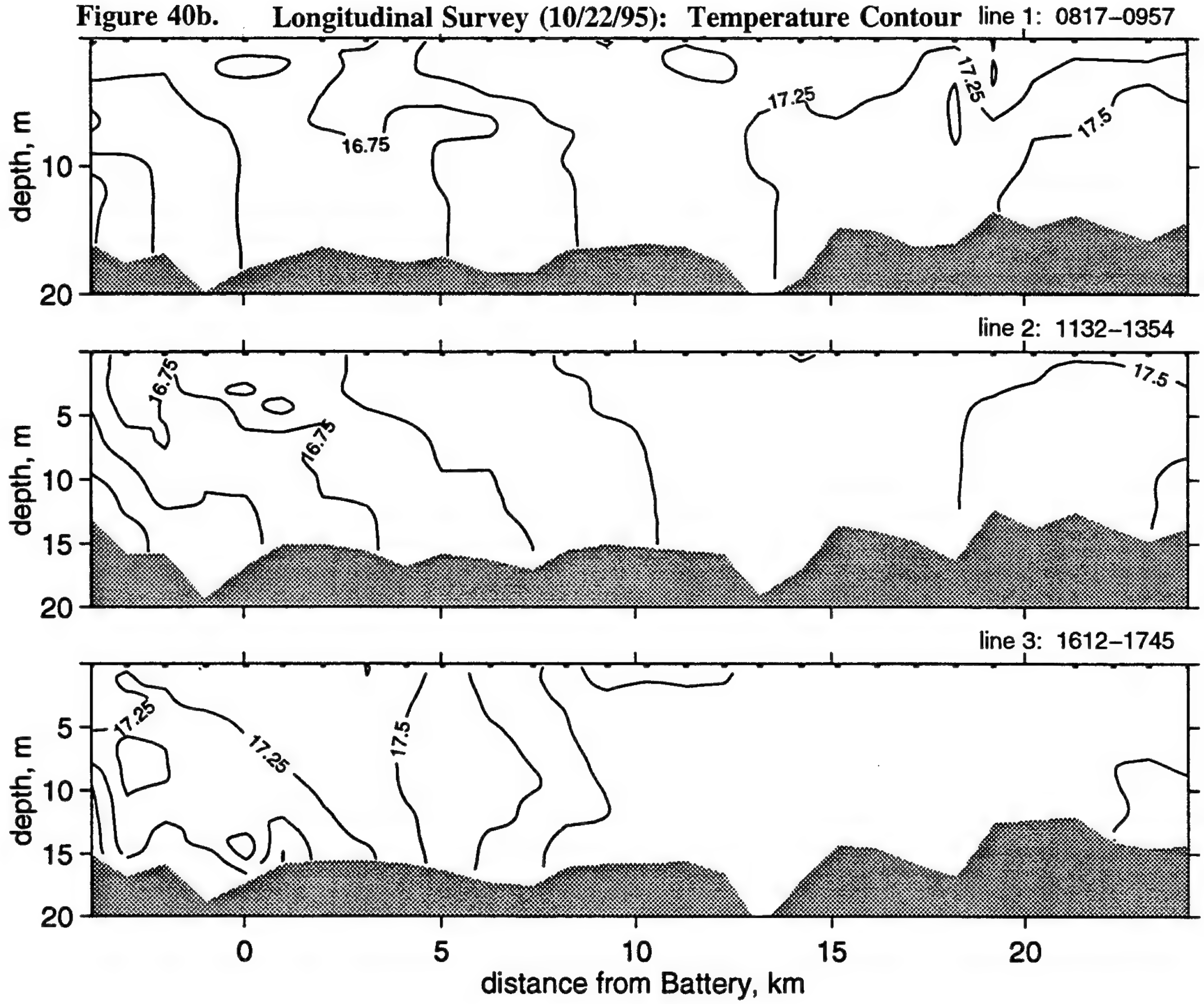
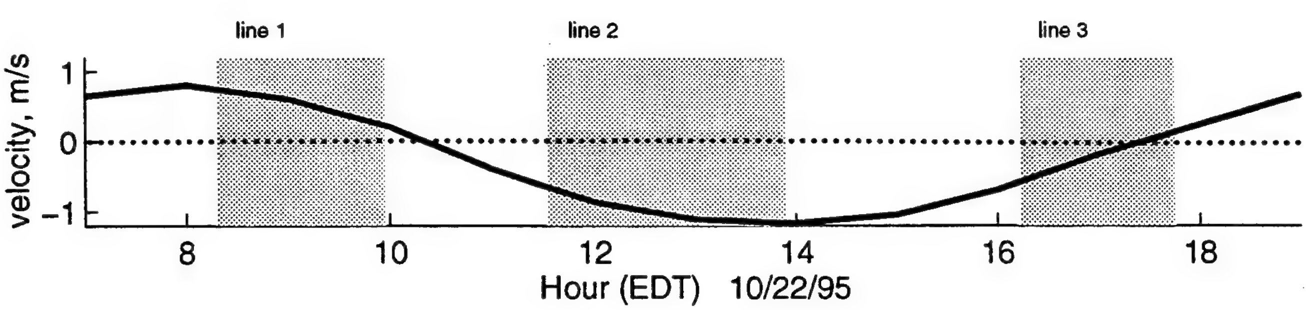


Figure 40b. Longitudinal Survey (10/22/95): Temperature Contour





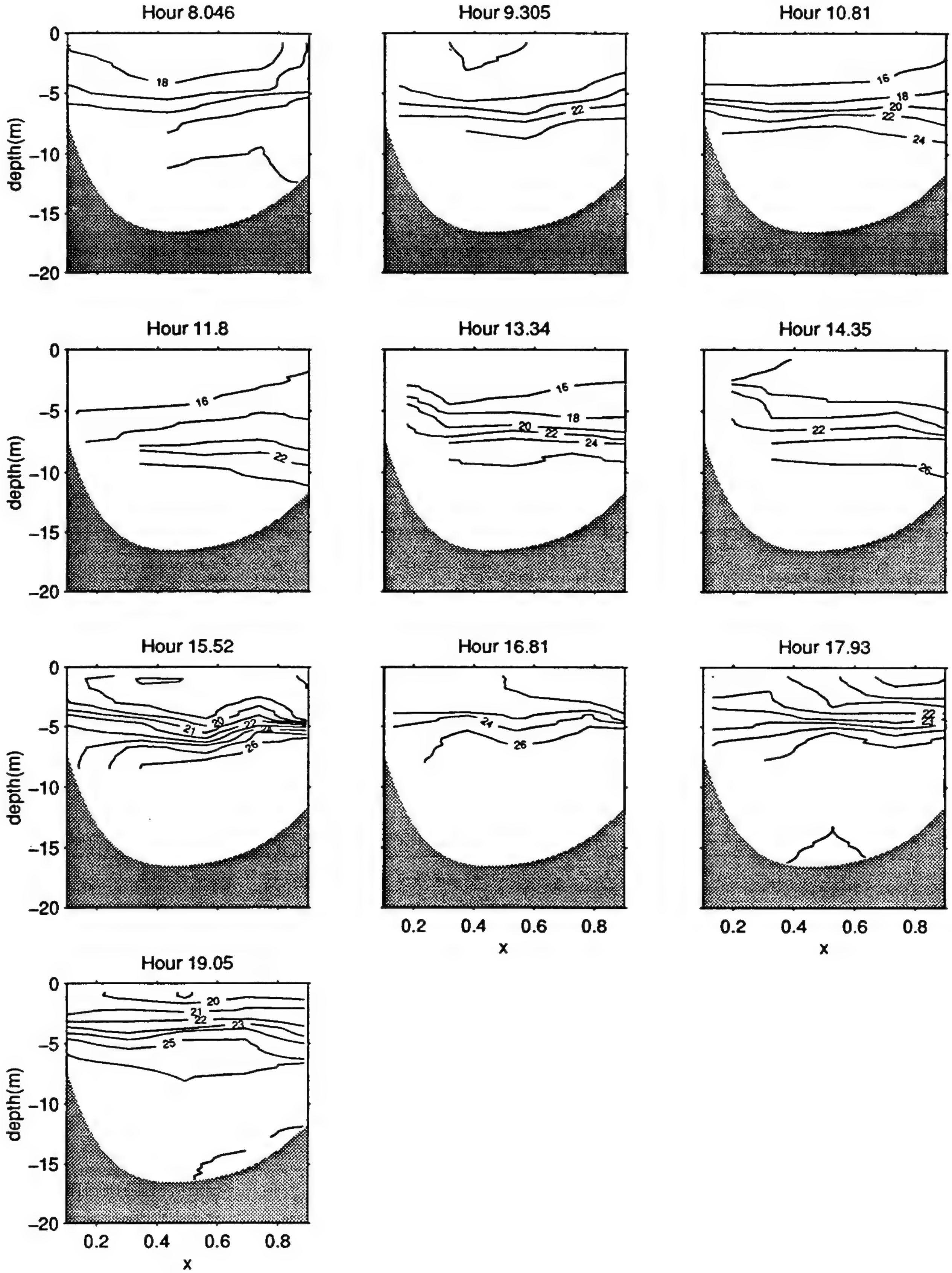


Figure 41a. South transect, salinity contours (psu) on 8/18/95

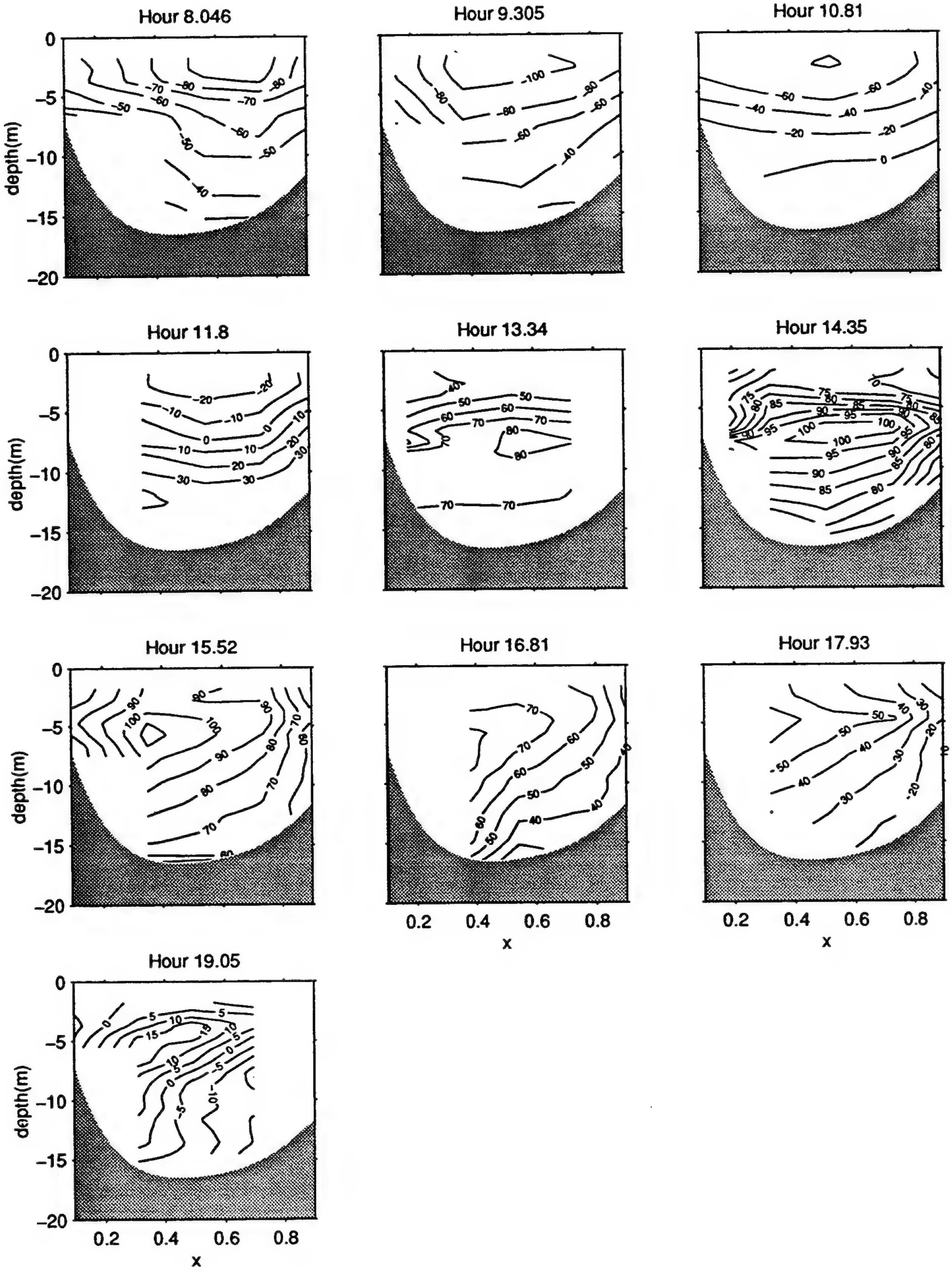


Figure 41b. South transect, velocity contours (cm/s) on 8/18/95

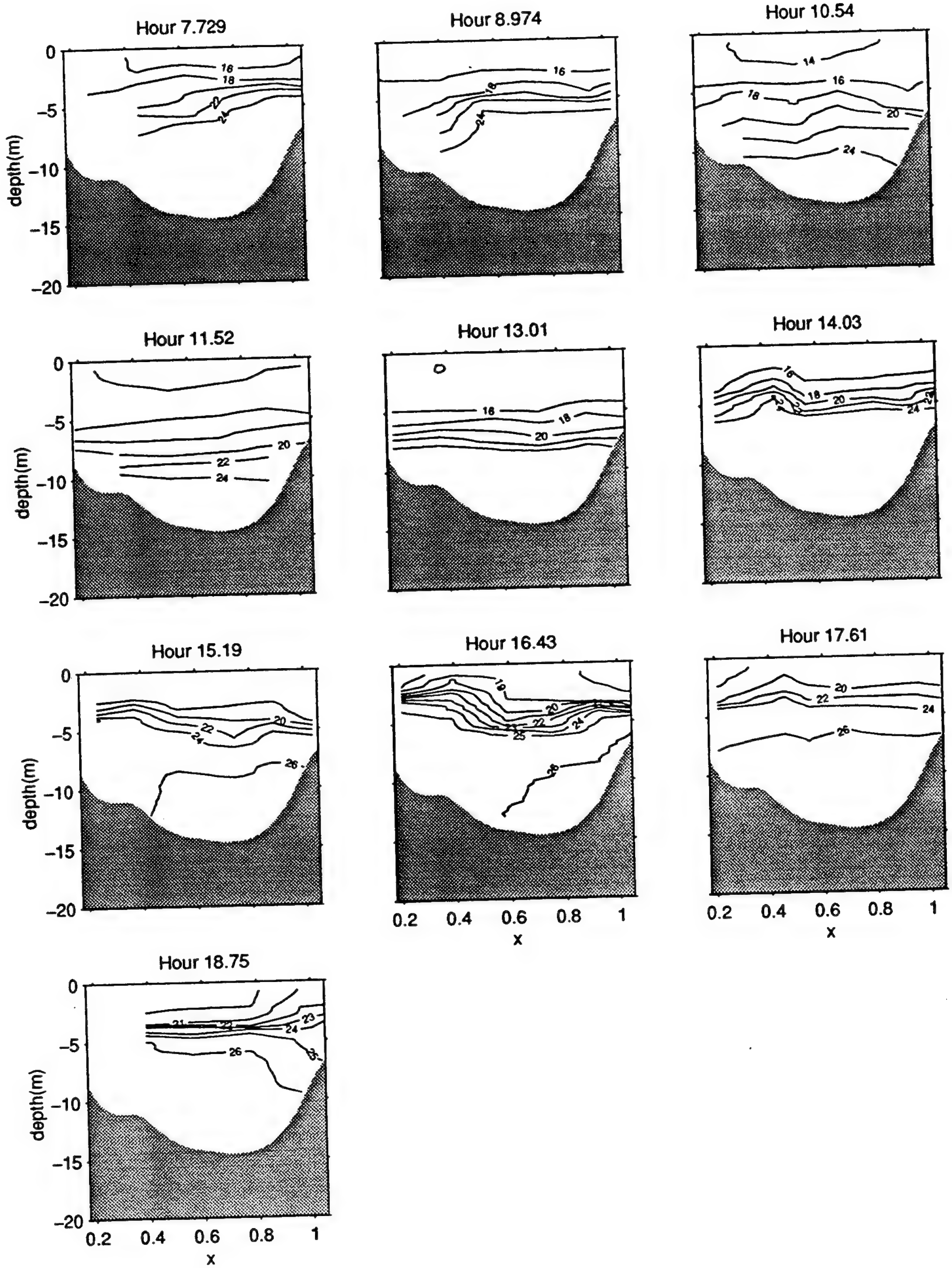


Figure 42a. Middle transect, salinity contours (psu) on 8/18/95

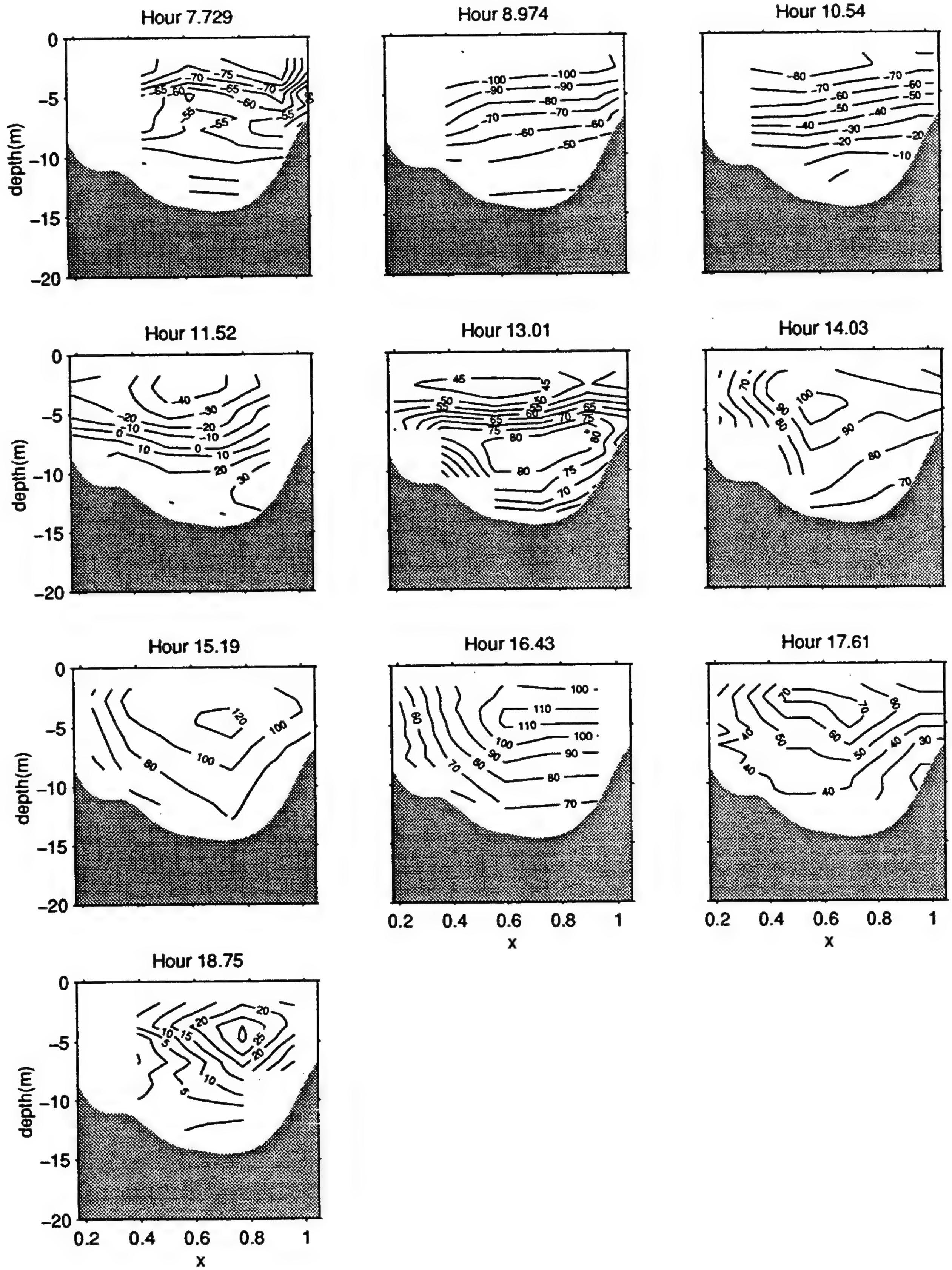


Figure 42b. Middle transect, velocity contours (cm/s) on 8/18/95

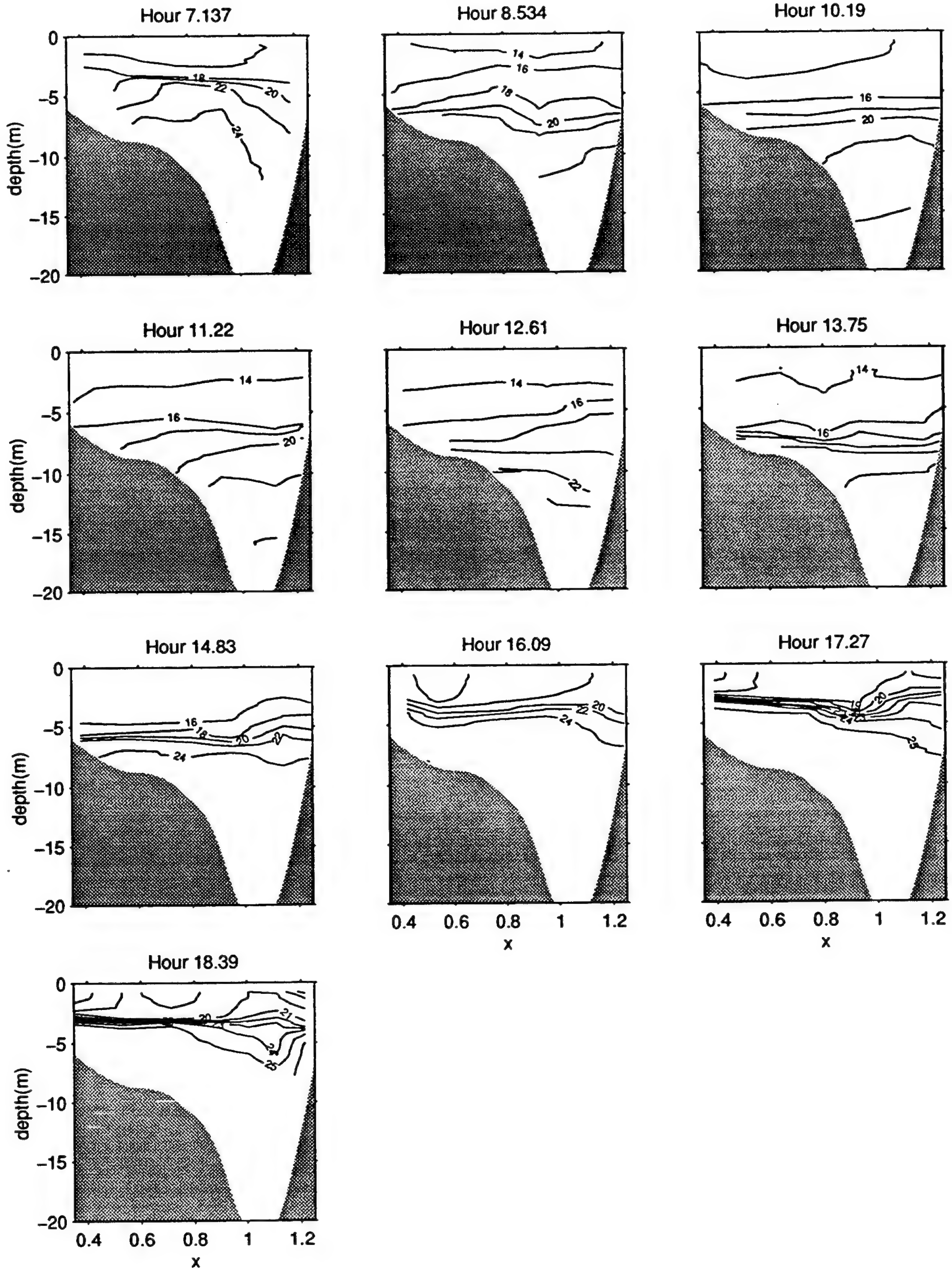


Figure 43a. North transect, salinity contours (psu) on 8/18/95

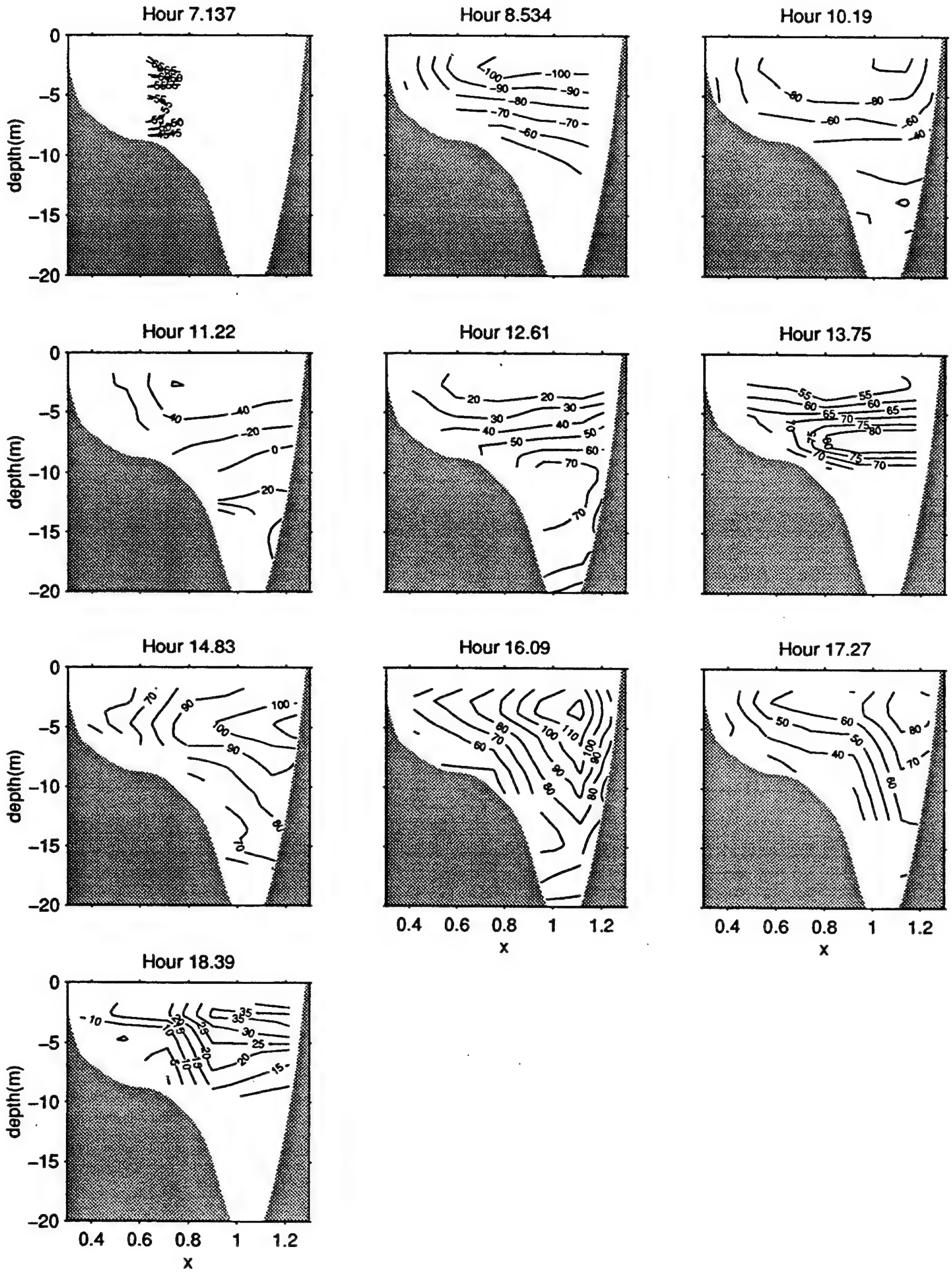


Figure 43b. North transect, velocity contours (cm/s) on 8/18/95

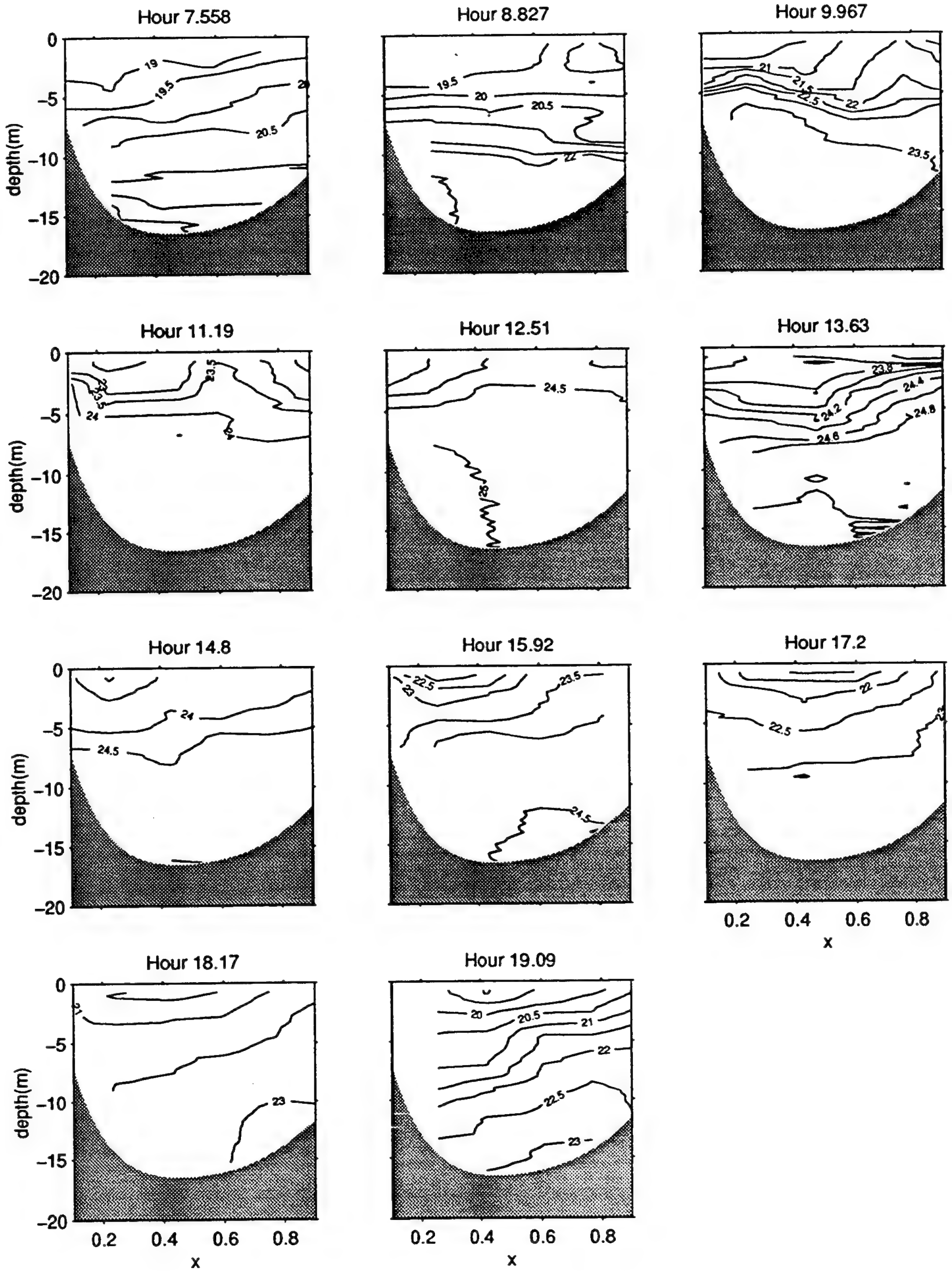


Figure 44a. South transect, salinity contours (psu) on 8/28/95

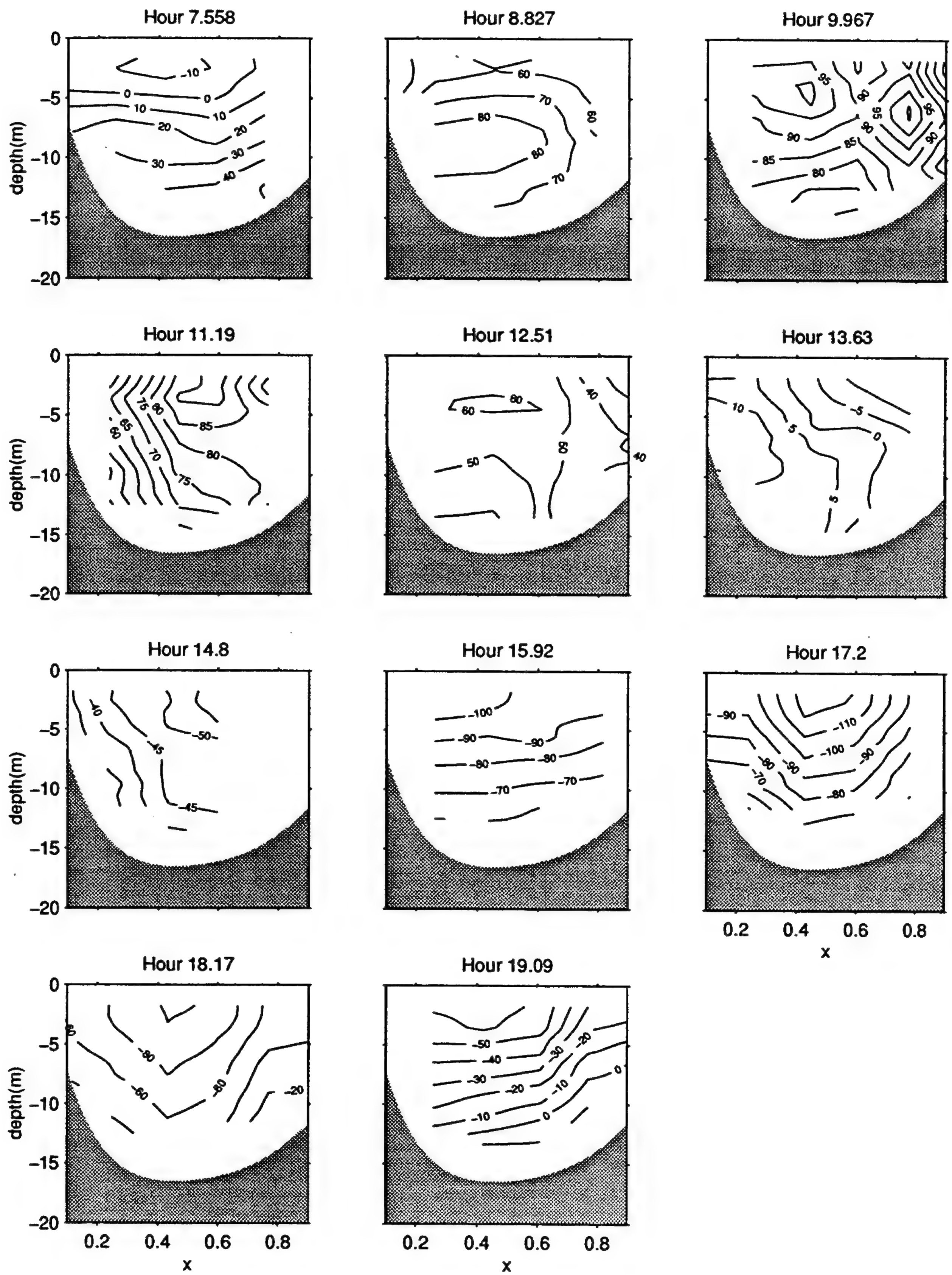


Figure 44b. South transect, velocity contours (cm/s) on 8/28/95

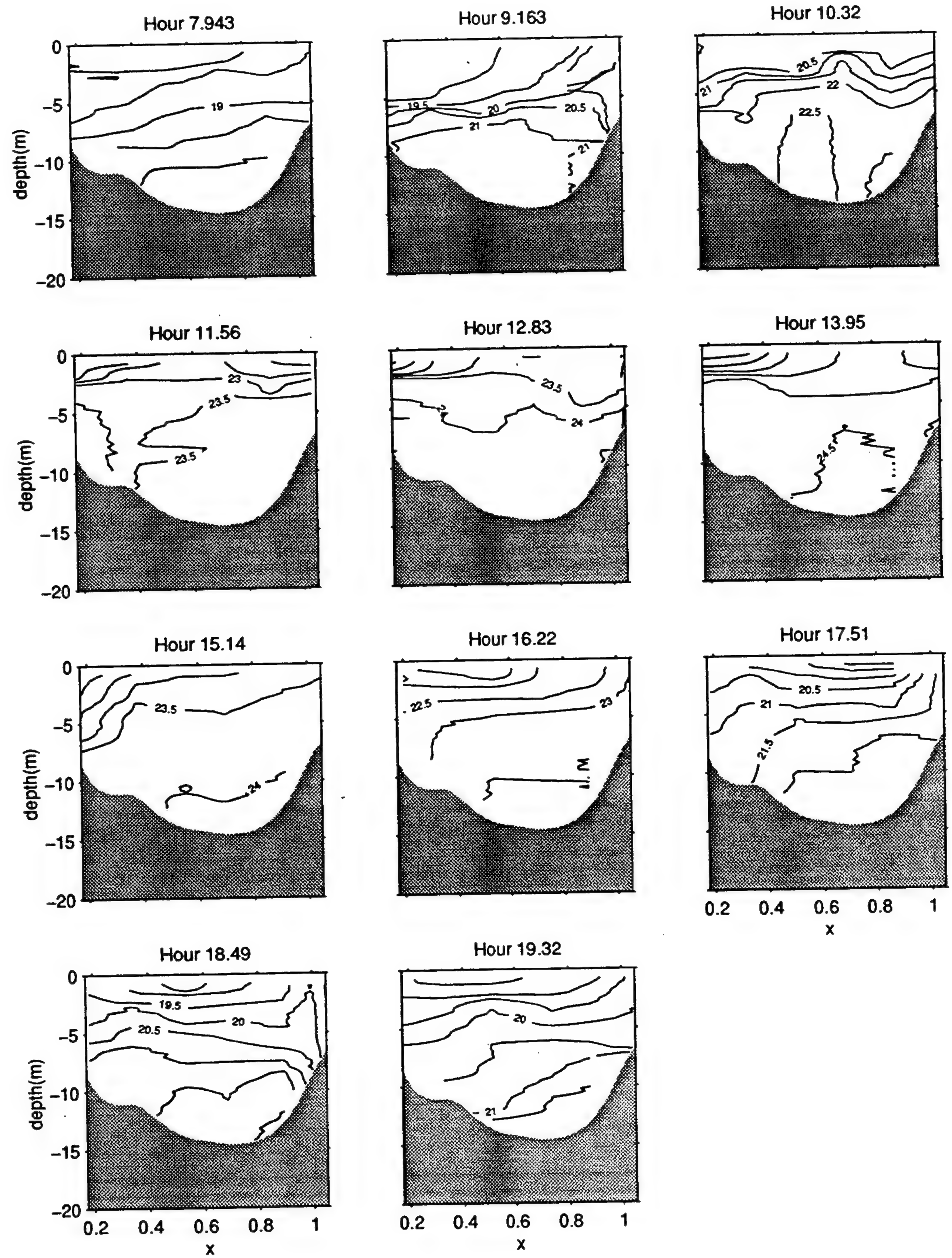


Figure 45a. Middle transect, salinity contours (psu) on 8/28/95

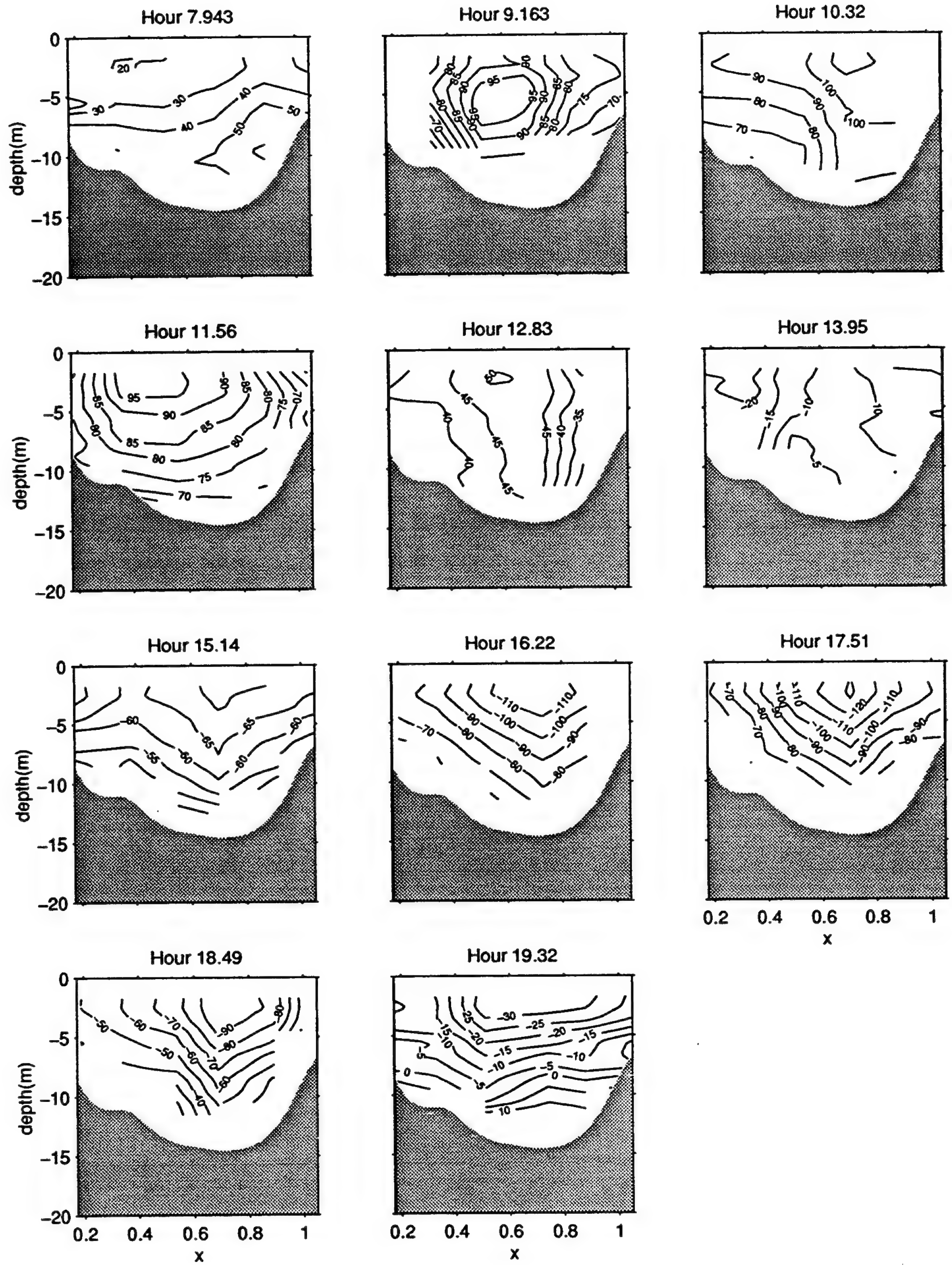


Figure 45b. Middle transect, velocity contours (cm/s) on 8/28/95

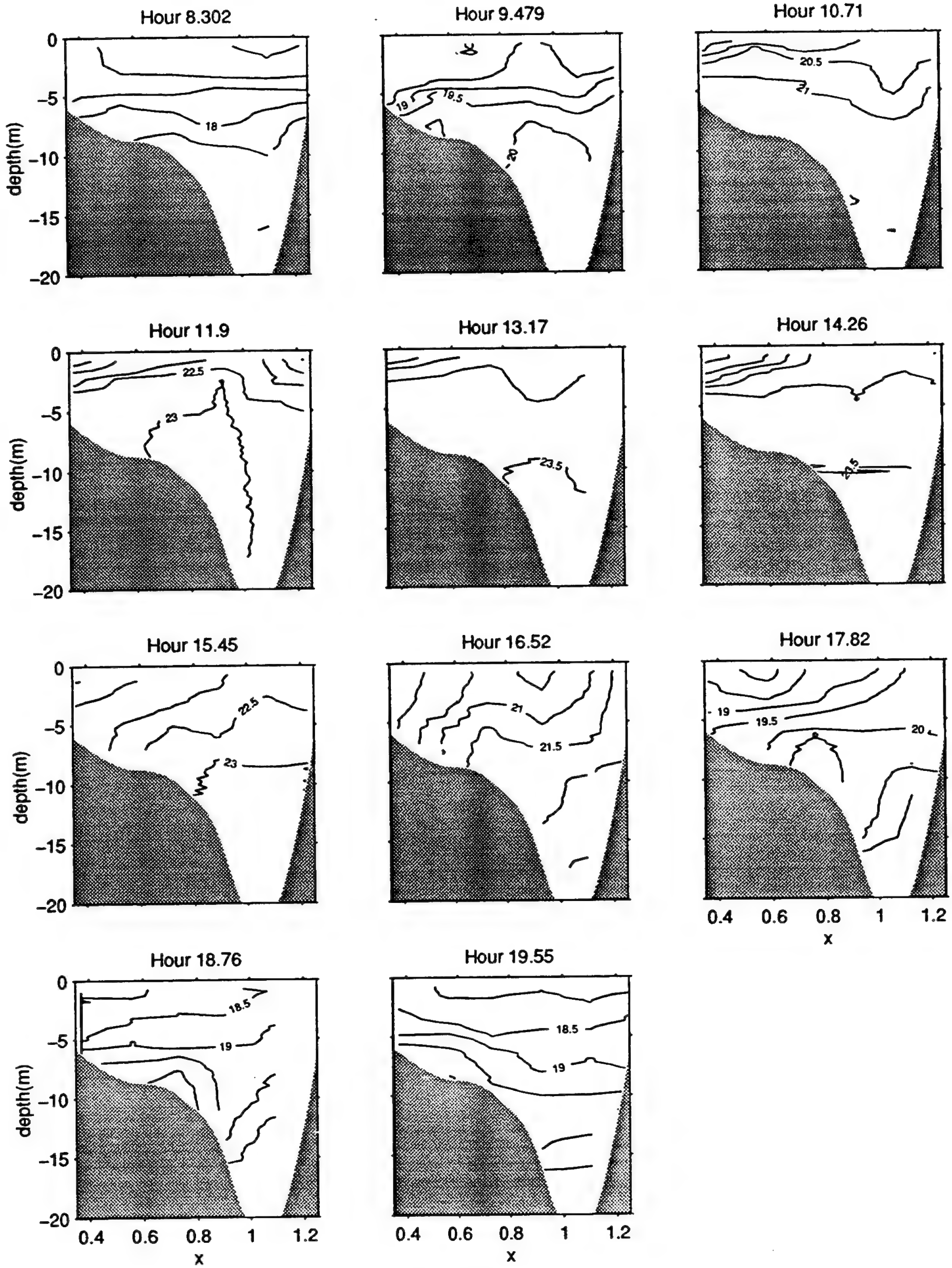


Figure 46a. North transect, salinity contours (psu) on 8/28/95

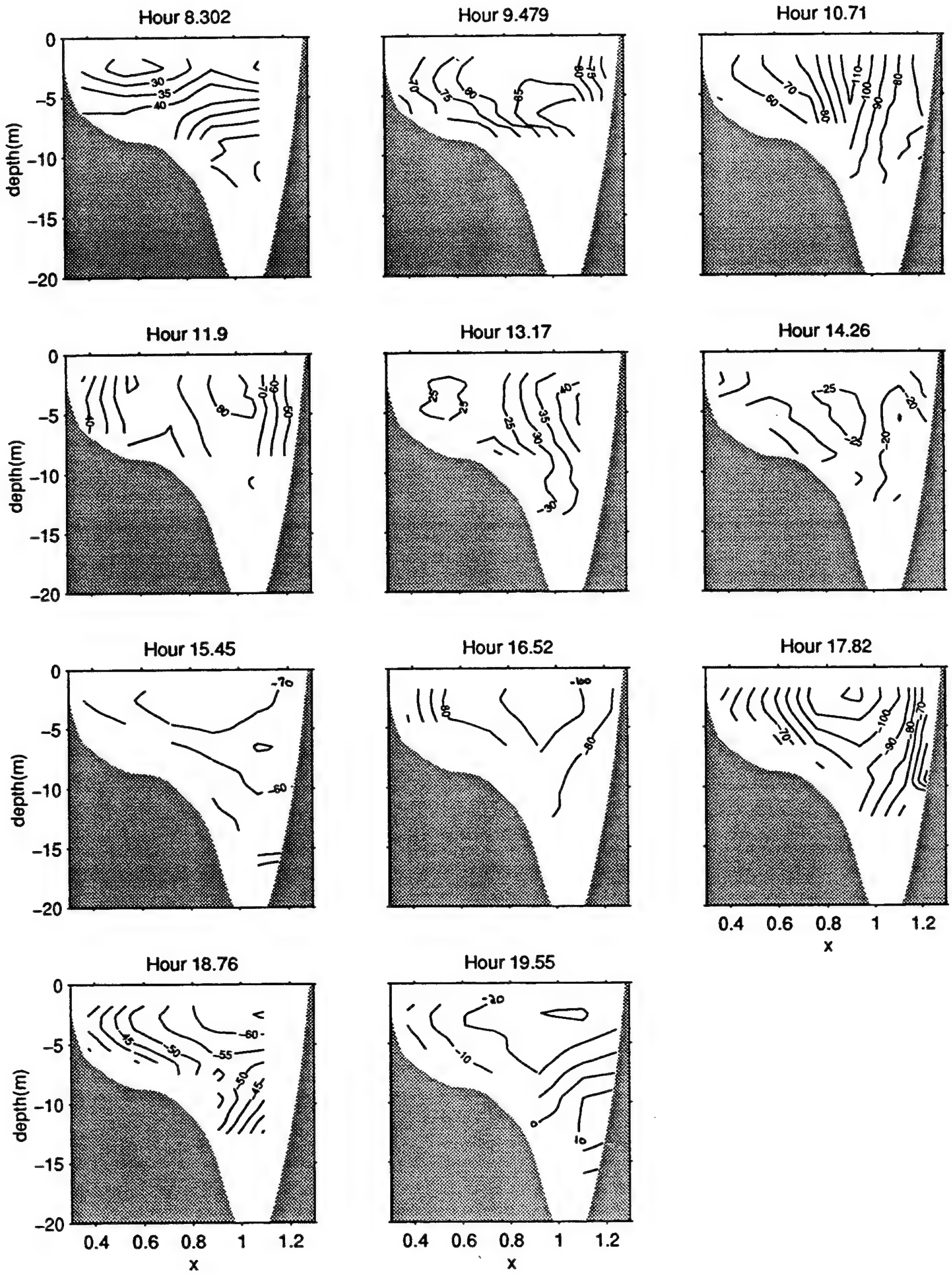


Figure 46b. North transect, velocity contours (cm/s) on 8/28/95

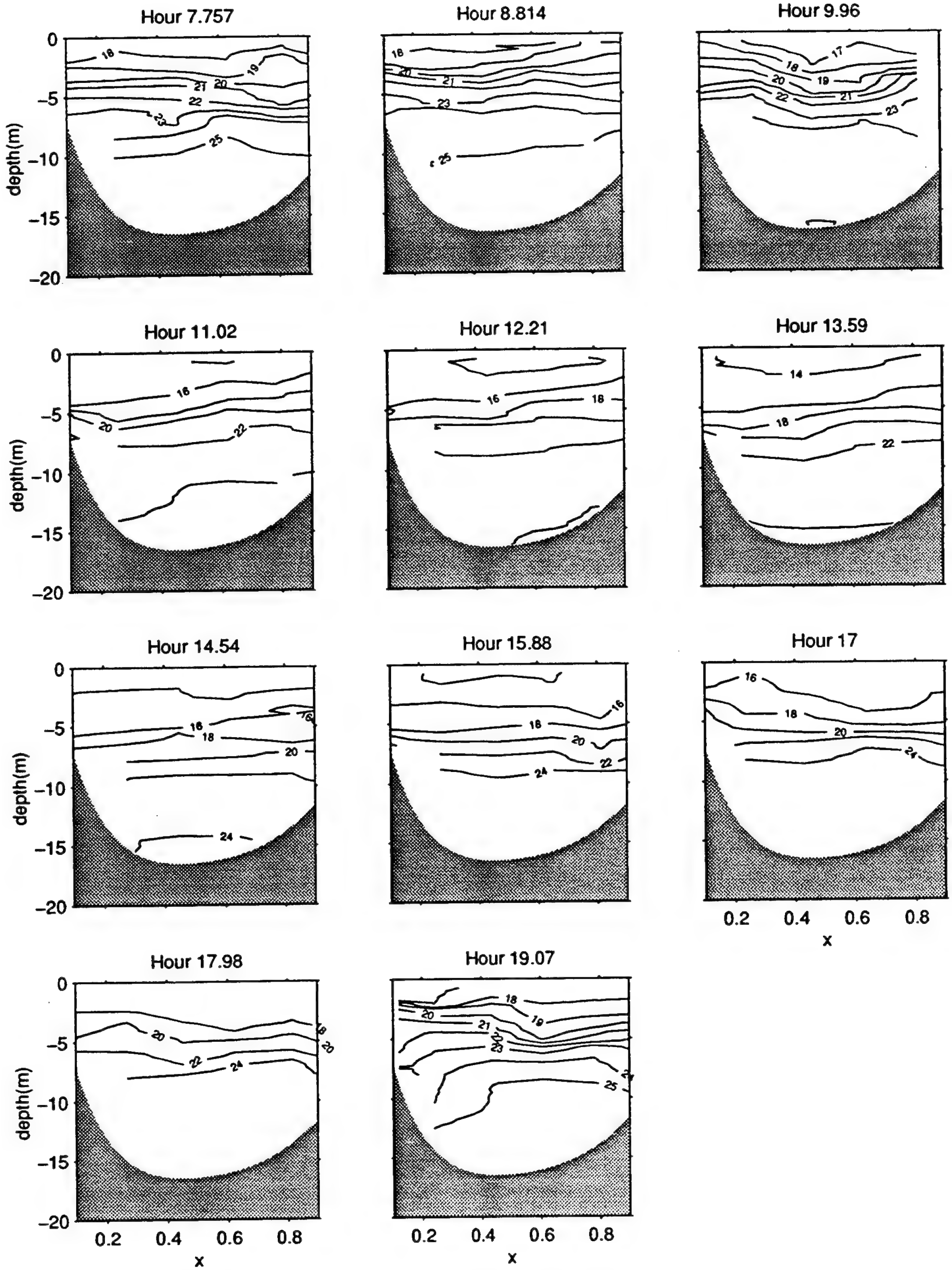


Figure 47a. South transect, salinity contours (psu) on 10/19/95

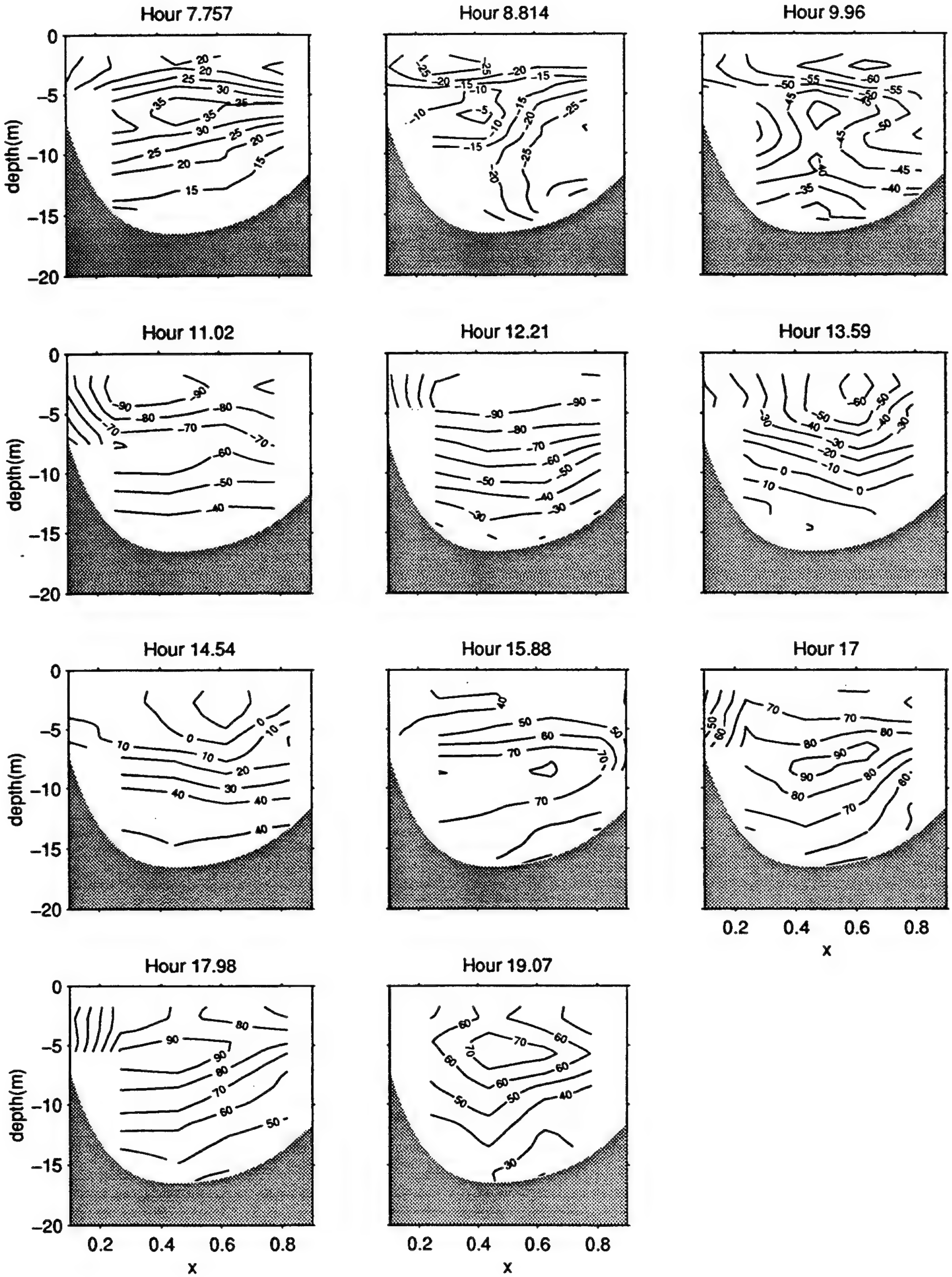


Figure 47b. South transect, velocity contours (cm/s) on 10/19/95

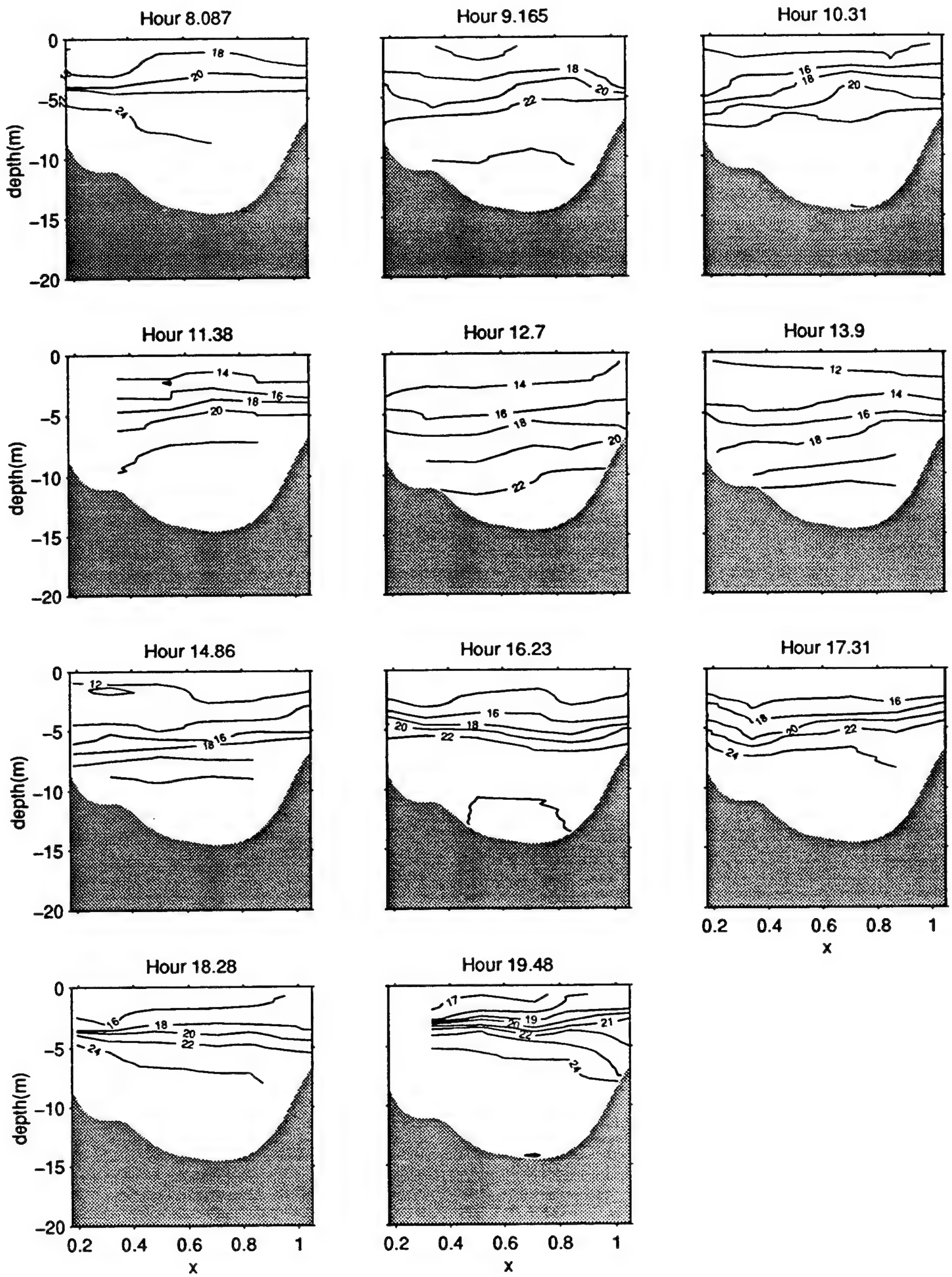


Figure 48a. Middle transect, salinity contours (psu) on 10/19/95

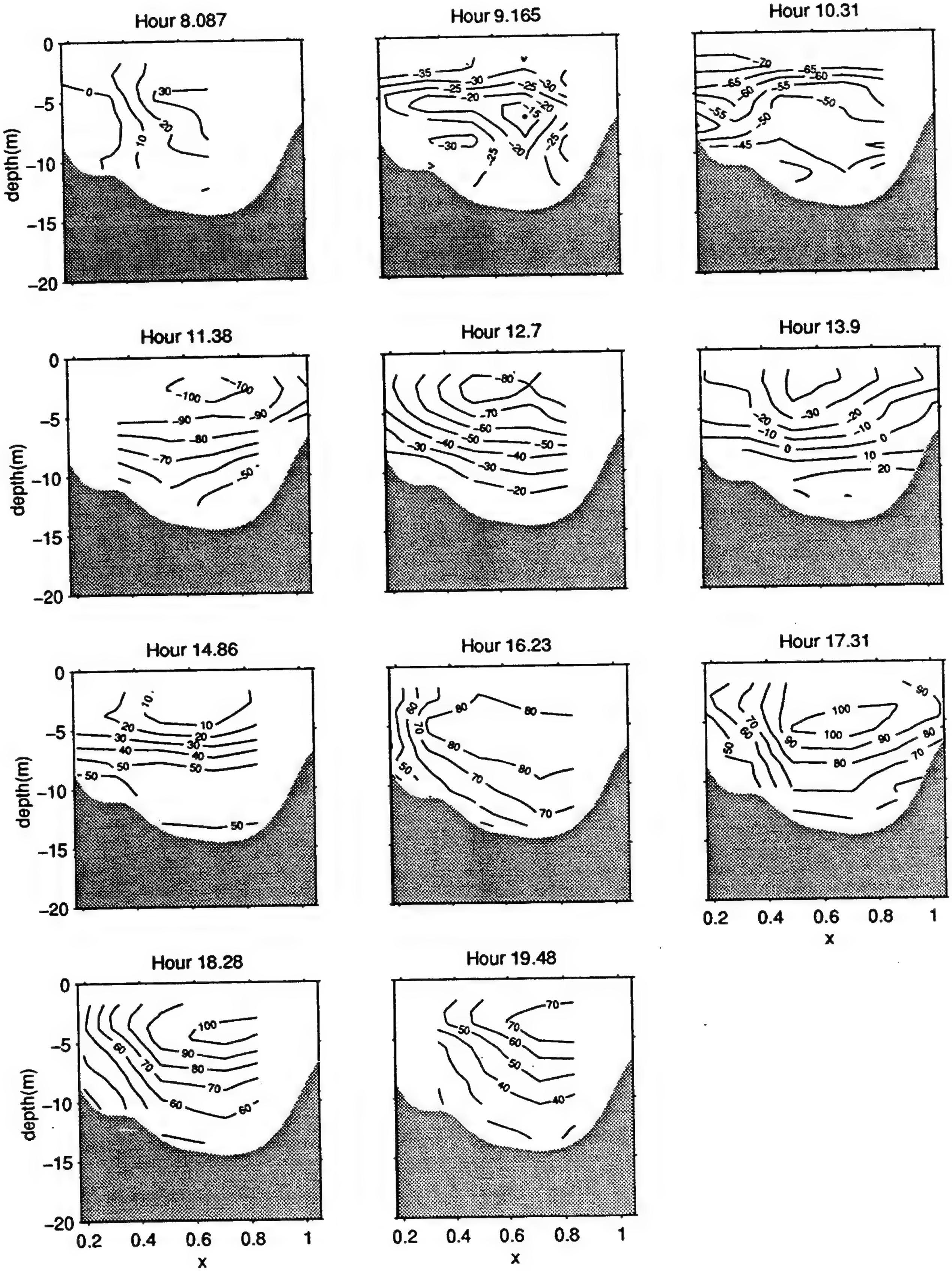


Figure 48b. Middle transect, velocity contours (cm/s) on 10/19/95

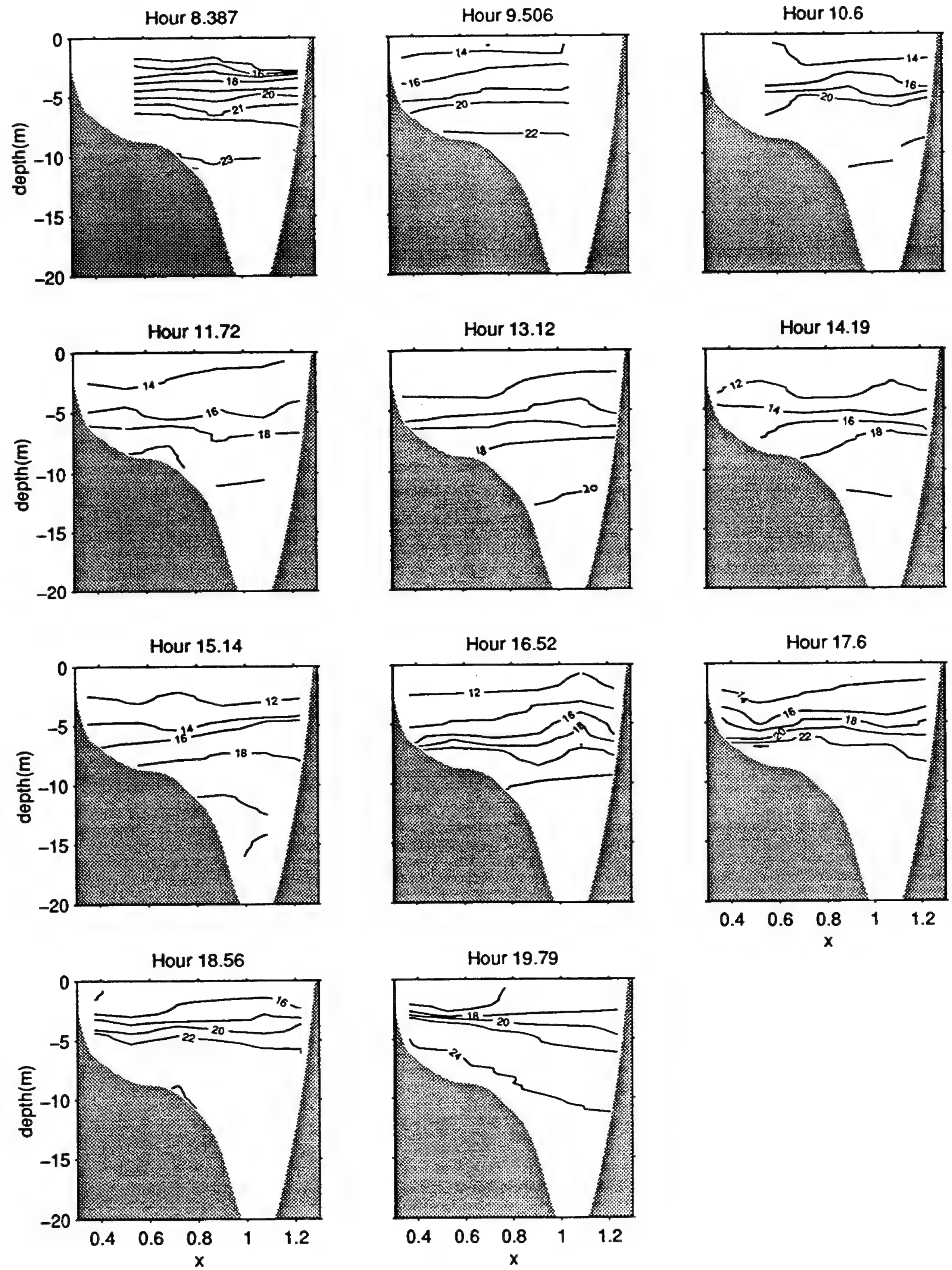


Figure 49a. North transect, salinity contours (psu) on 10/19/95

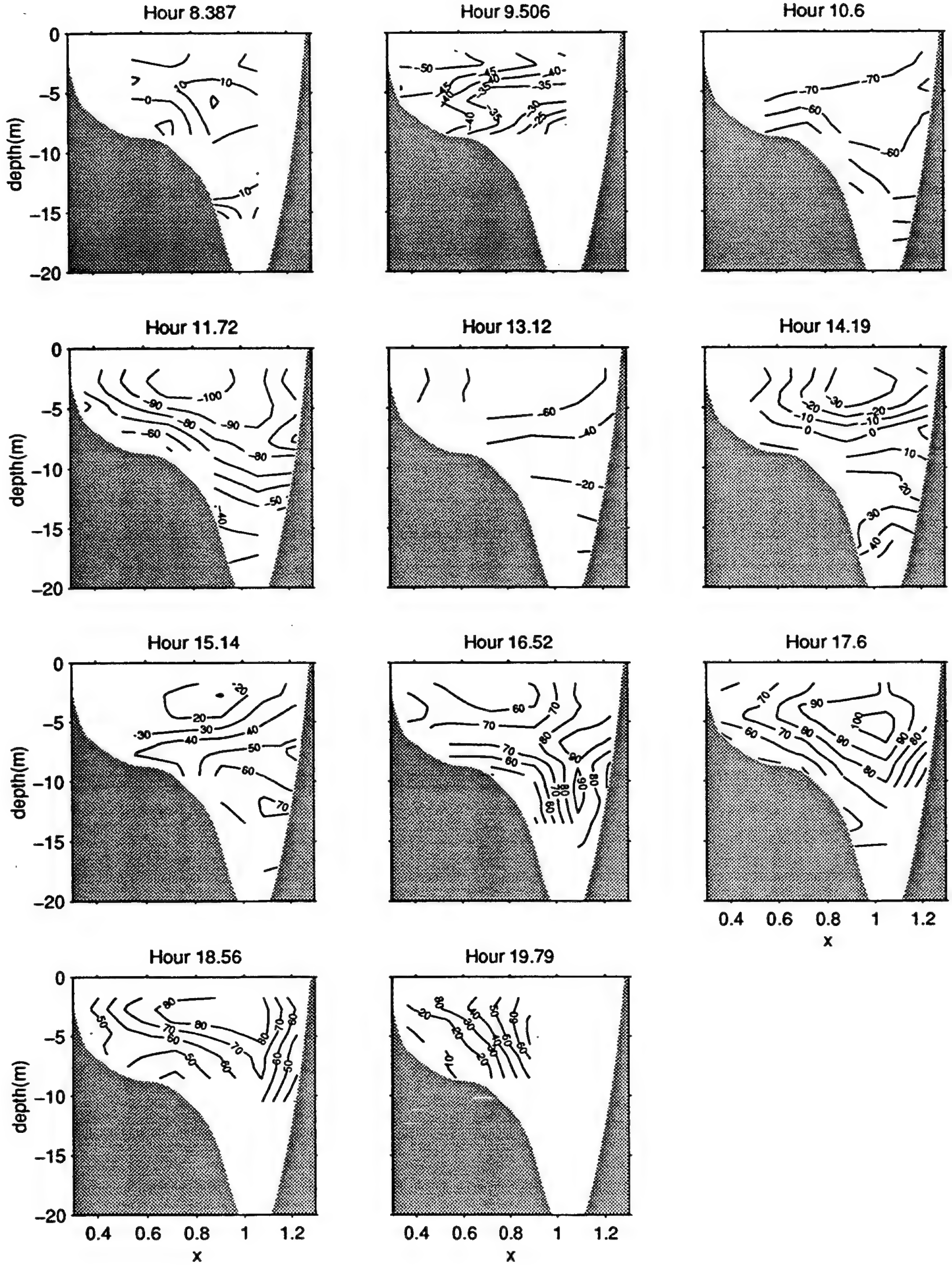


Figure 49b. North transect, velocity contours (cm/s) on 10/19/95

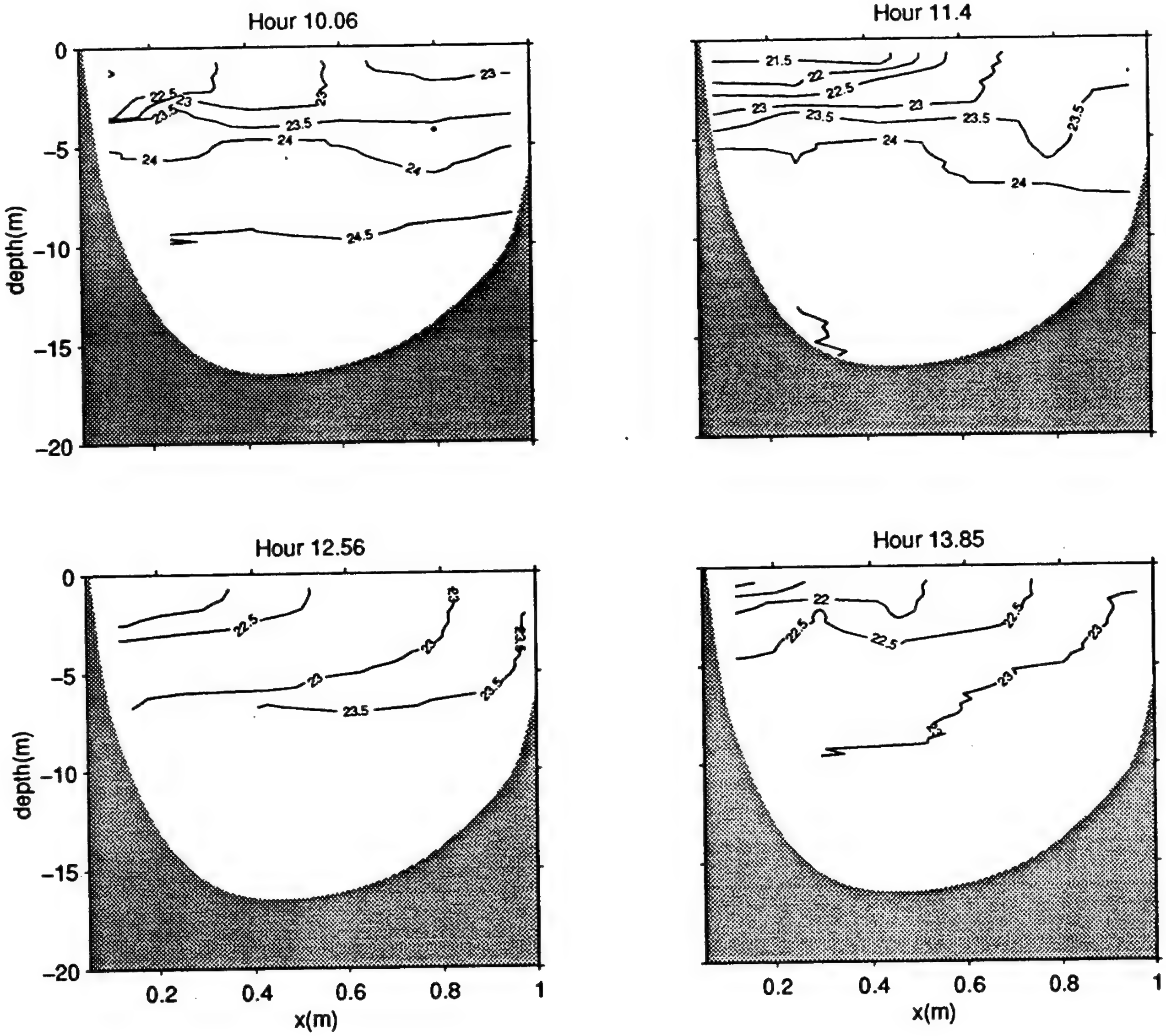


Figure 50a. South transect, salinity contours (psu) on 10/21/95

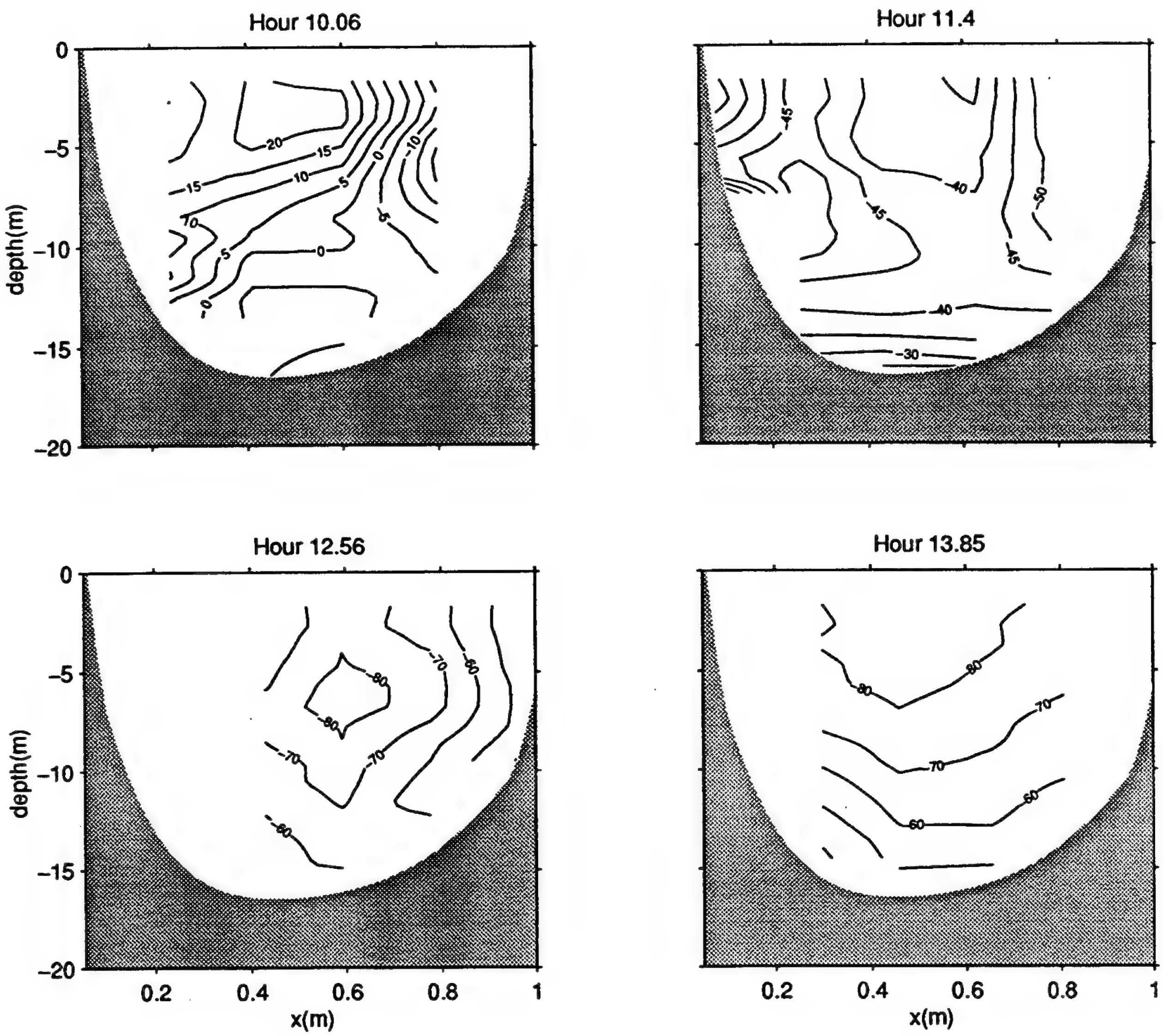


Figure 50b. South transect, velocity contours (cm/s) on 10/21/95

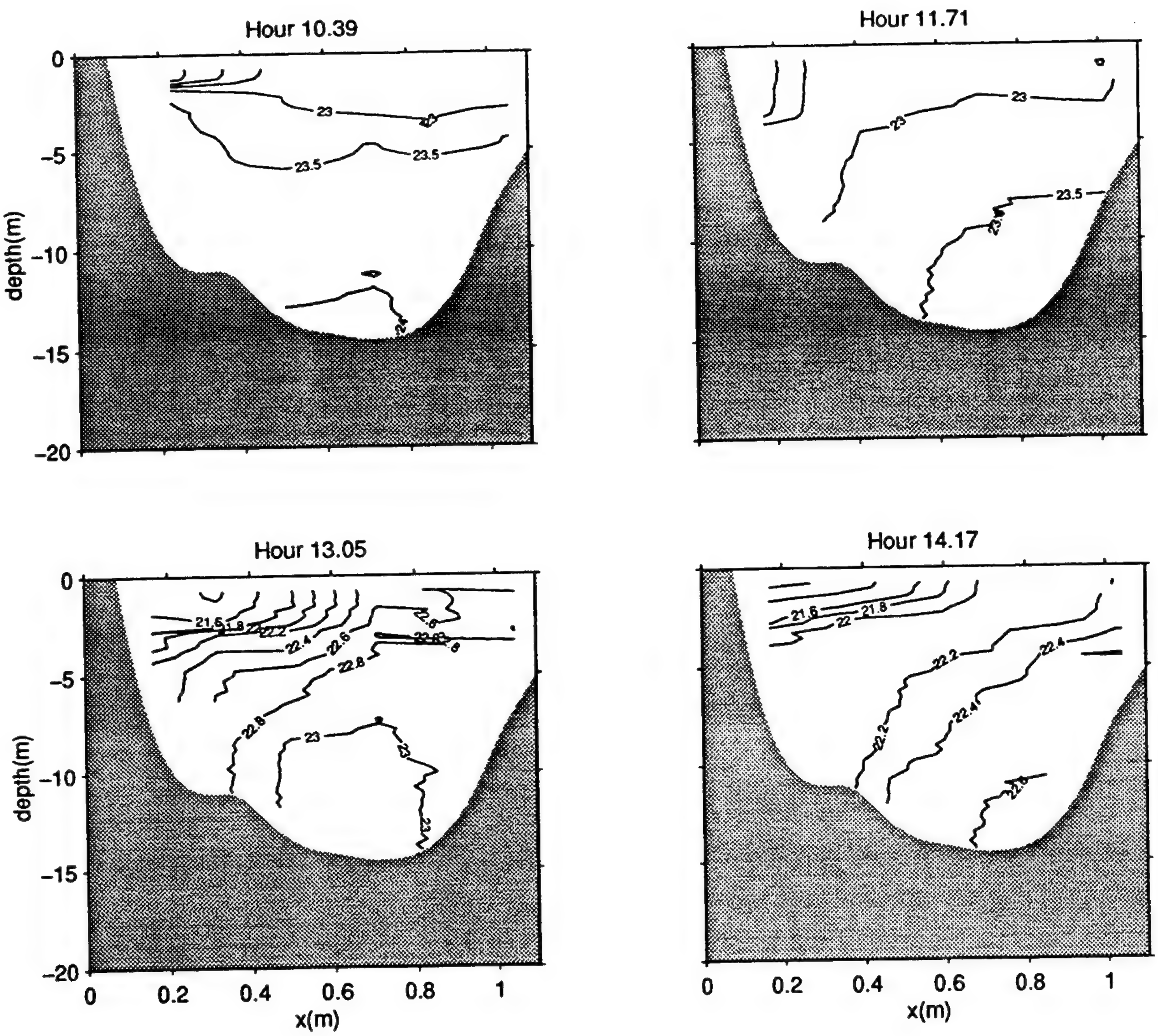


Figure 51a. Middle transect, salinity contours (psu) on 10/21/95

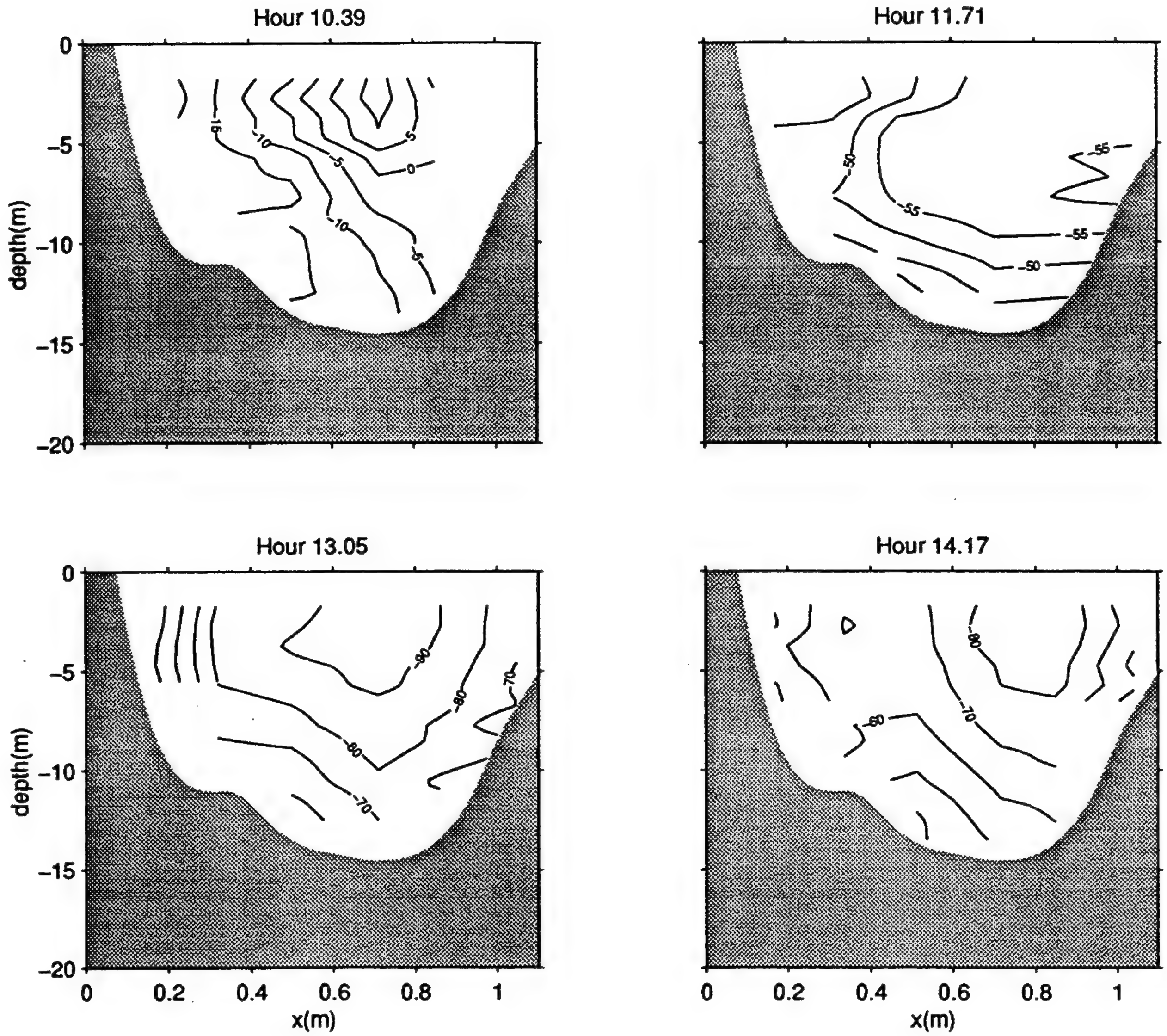


Figure 51b. Middle transect, velocity contours (cm/s) on 10/21/95

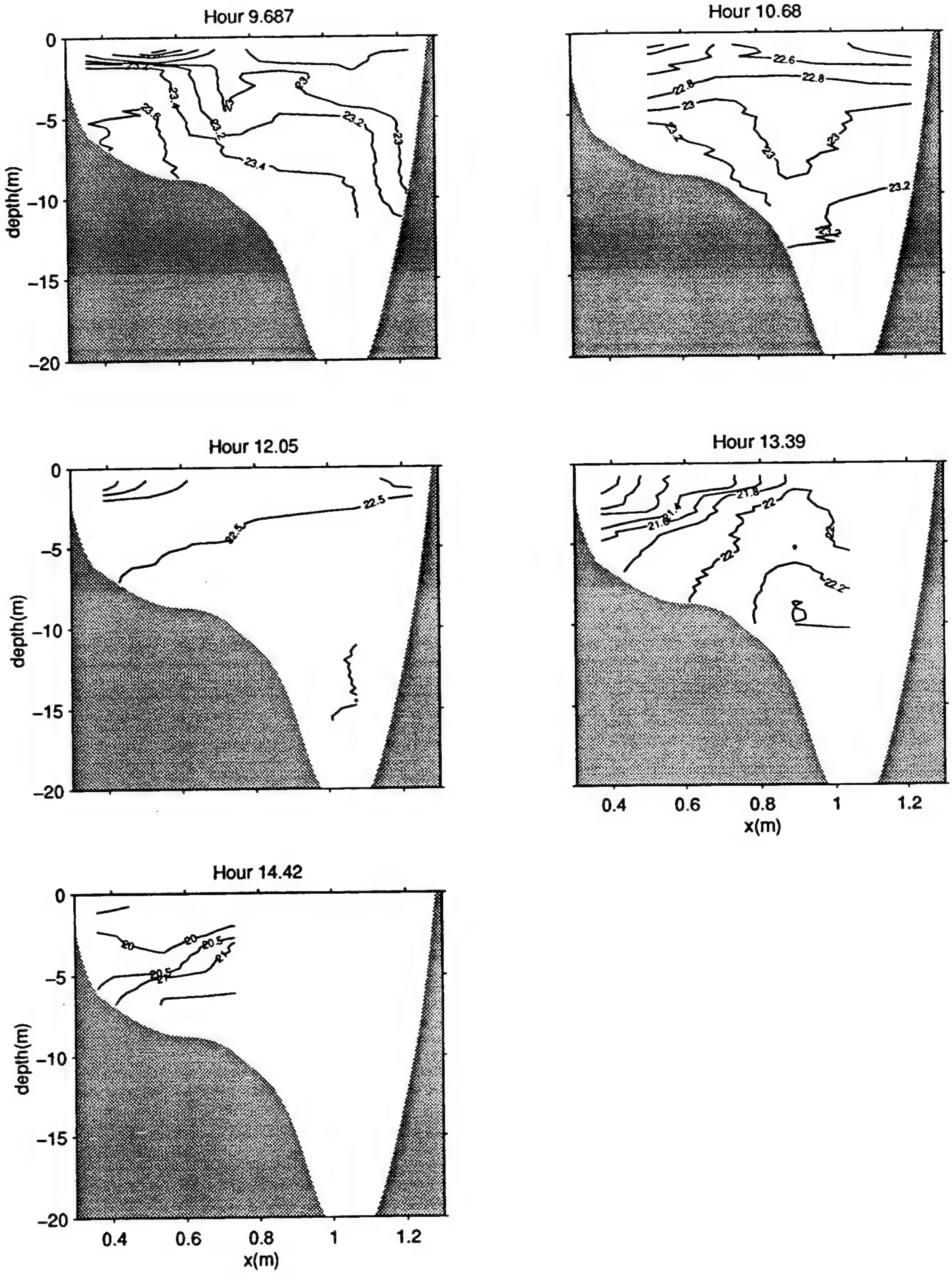


Figure 52a. North transect, salinity contours (psu) on 10/21/95

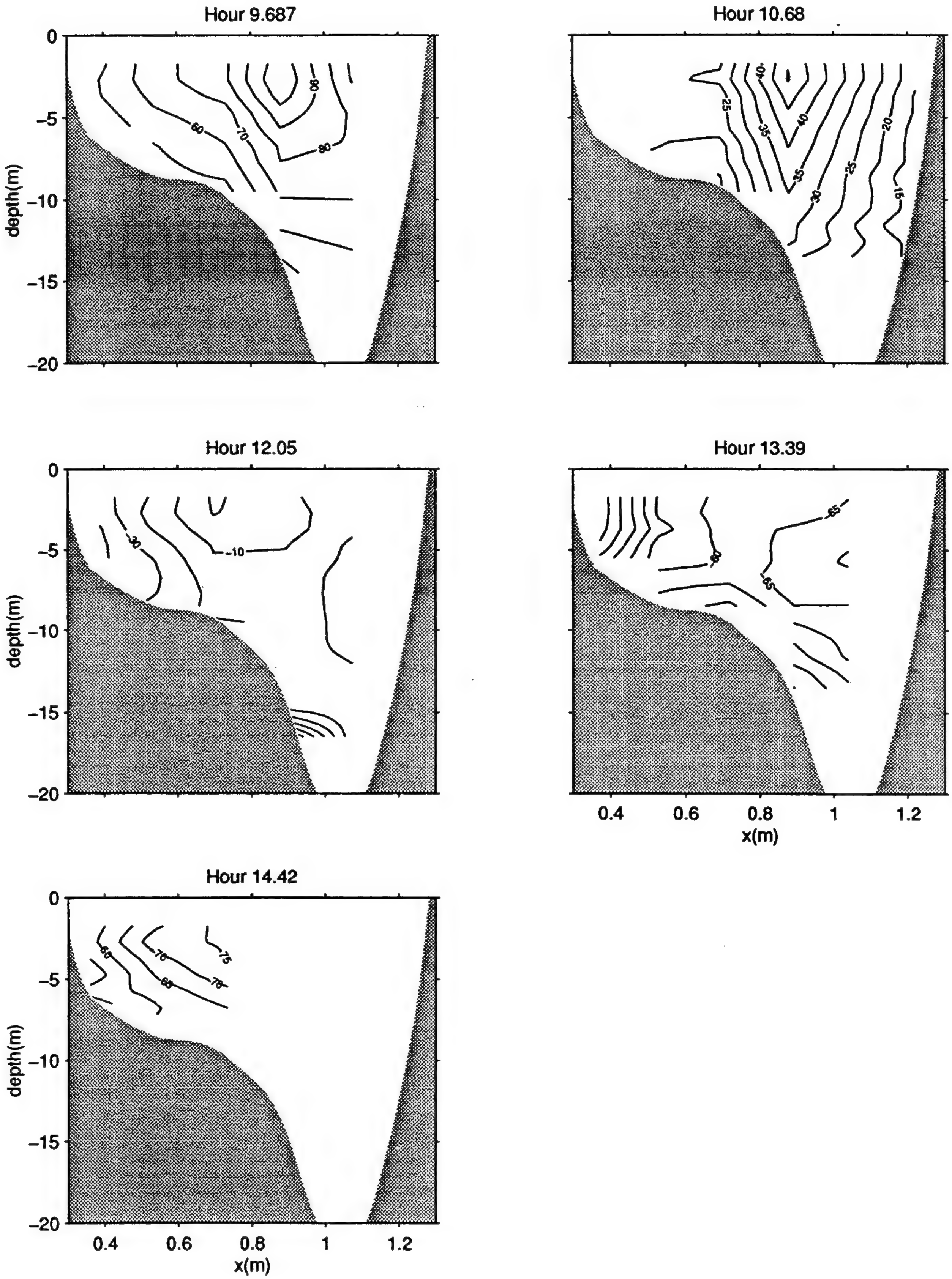


Figure 52b. North transect, velocity contours (cm/s) on 10/21/95

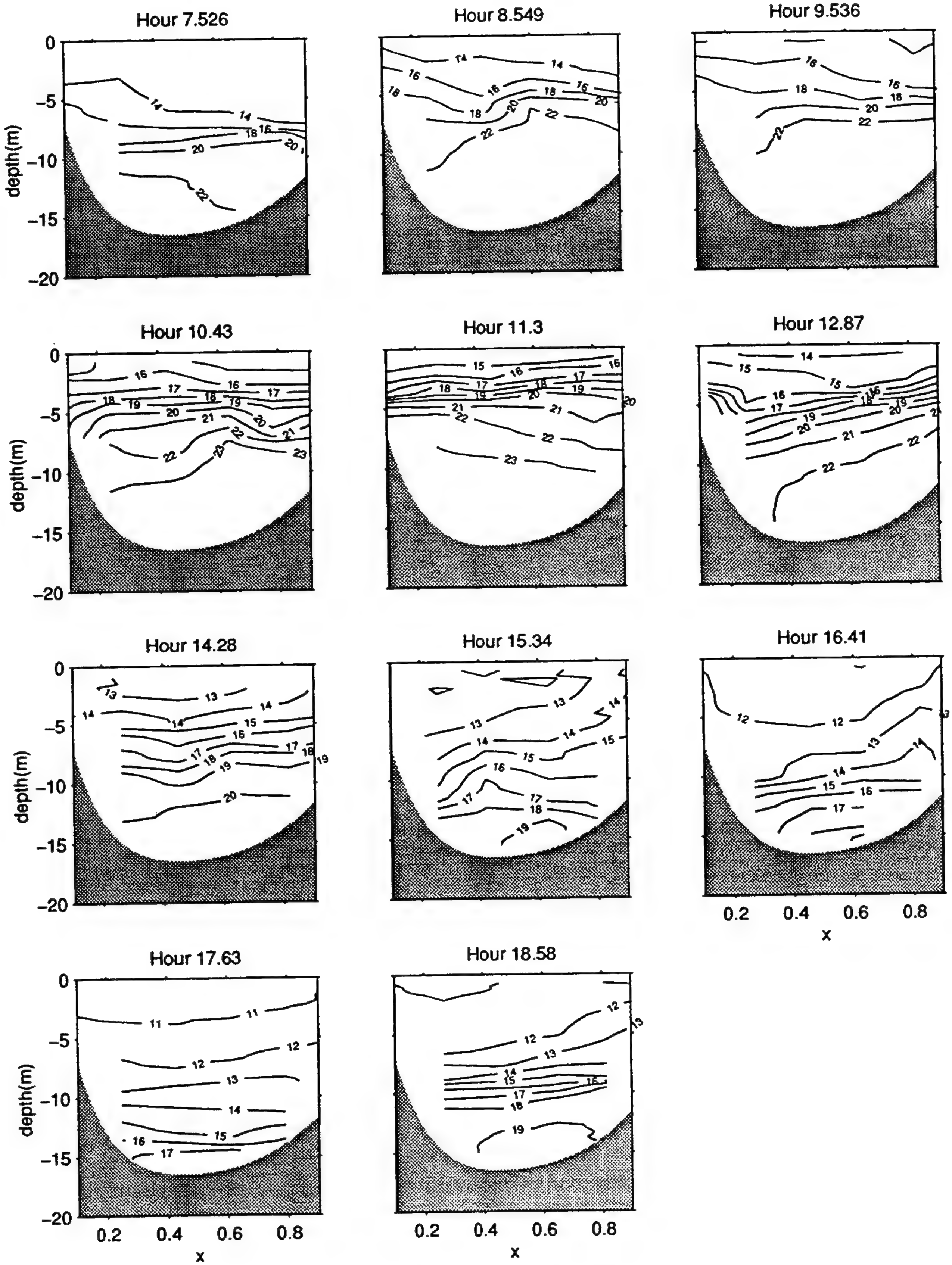


Figure 53a. South transect, salinity contours (psu) on 10/23/95

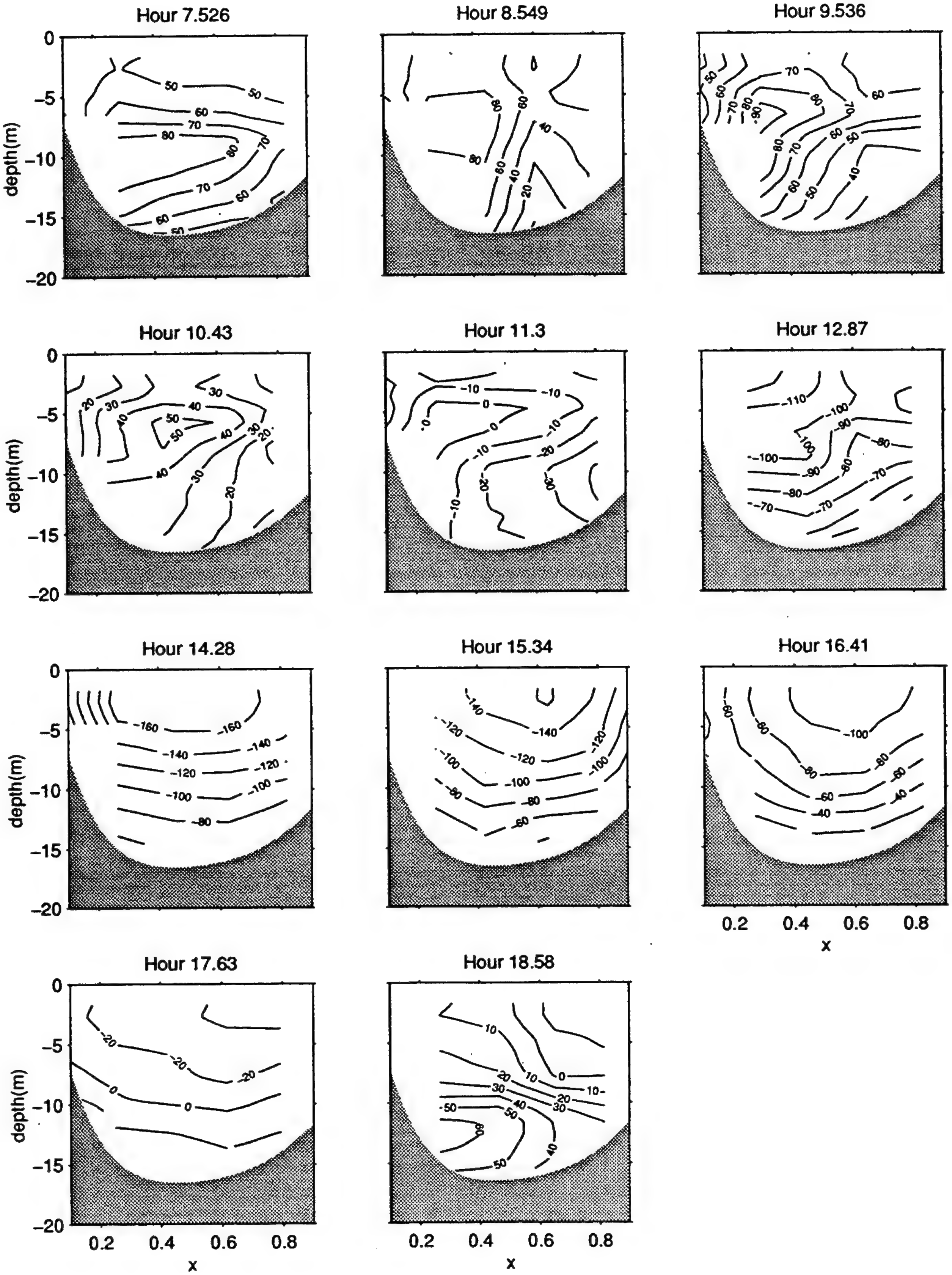


Figure 53b. South transect, velocity contours (cm/s) on 10/23/95

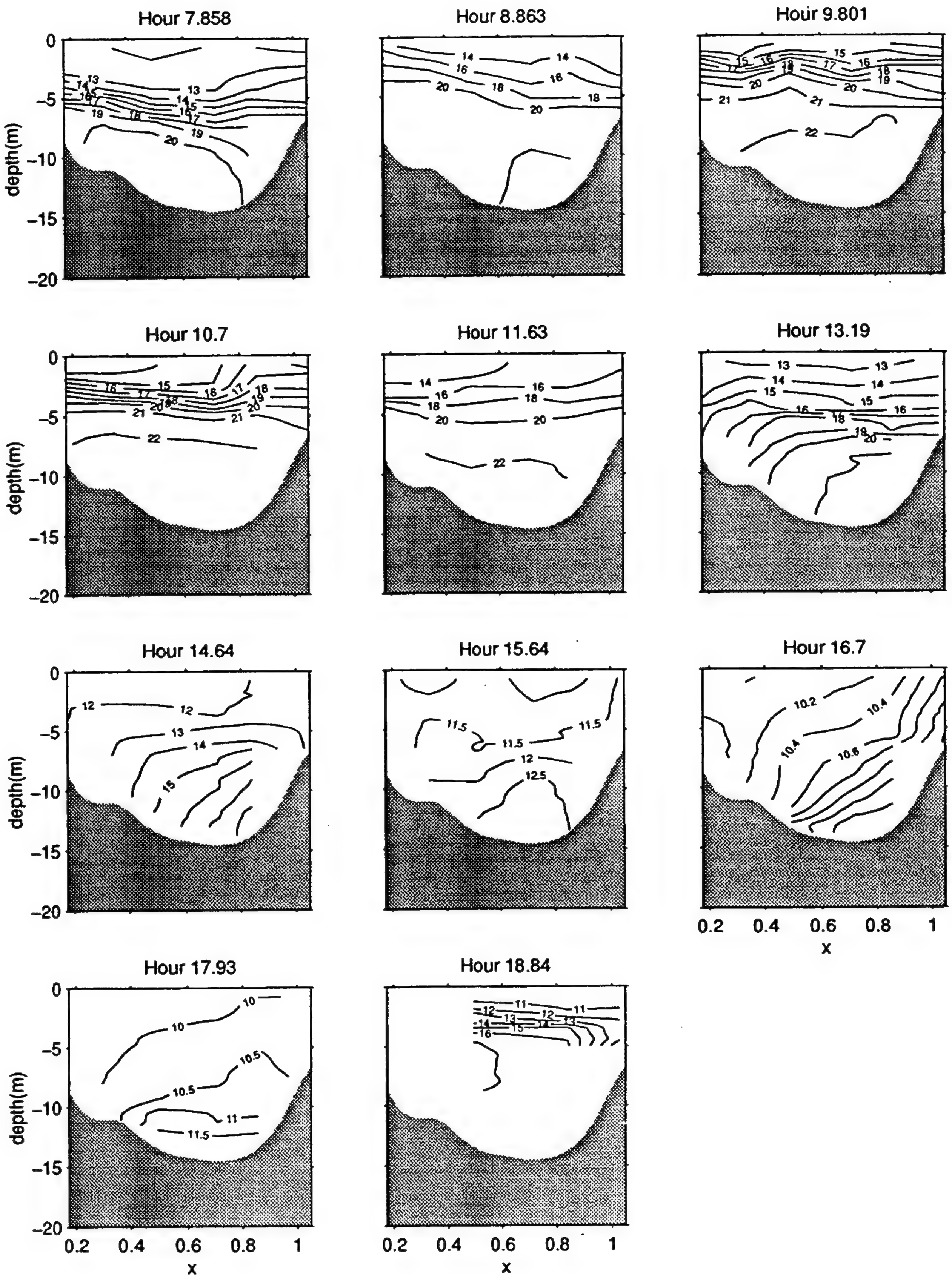


Figure 54a. Middle transect, salinity contours (psu) on 10/23/95

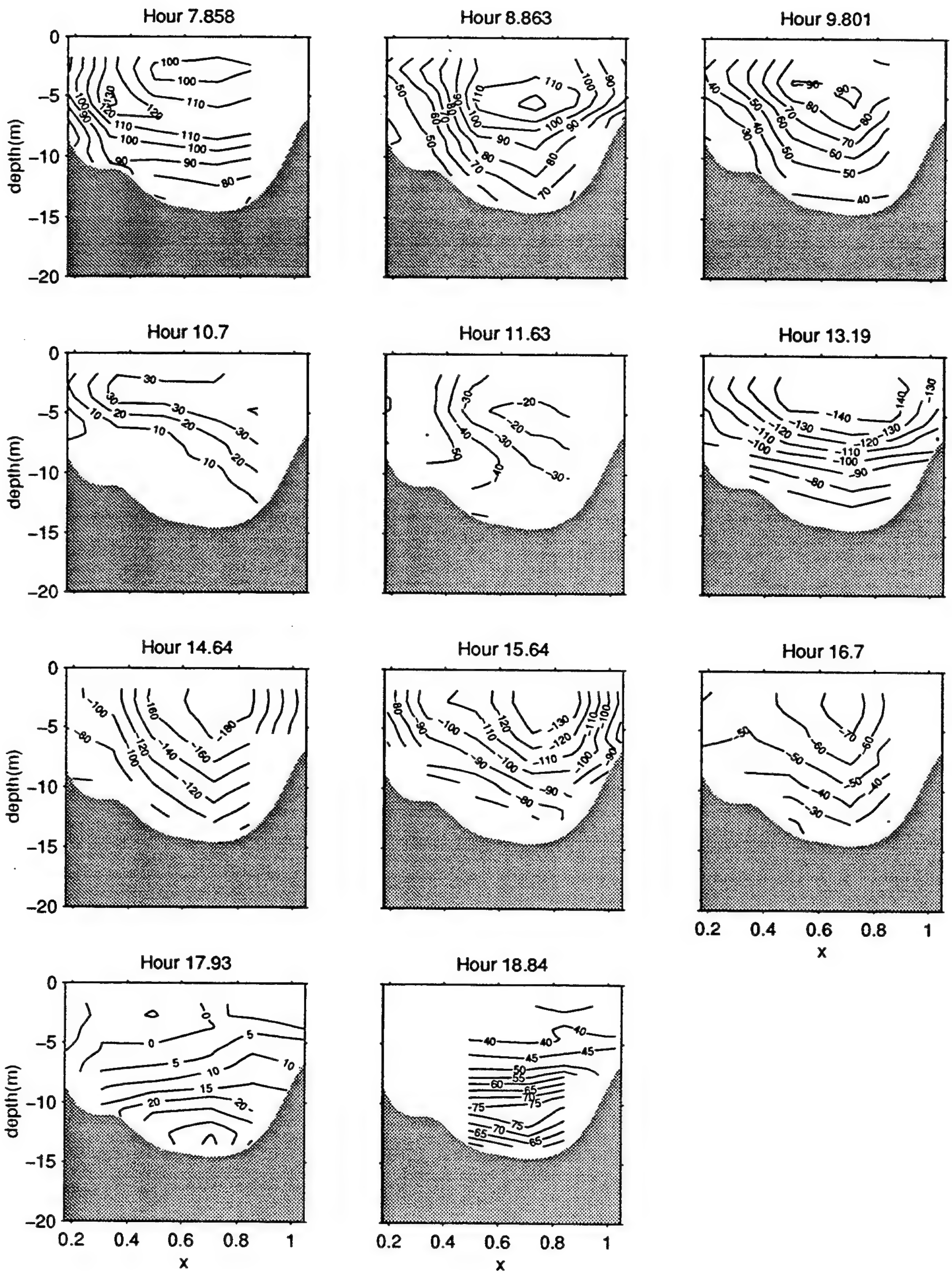


Figure 54b. Middle transect, velocity contours (cm/s) on 10/23/95

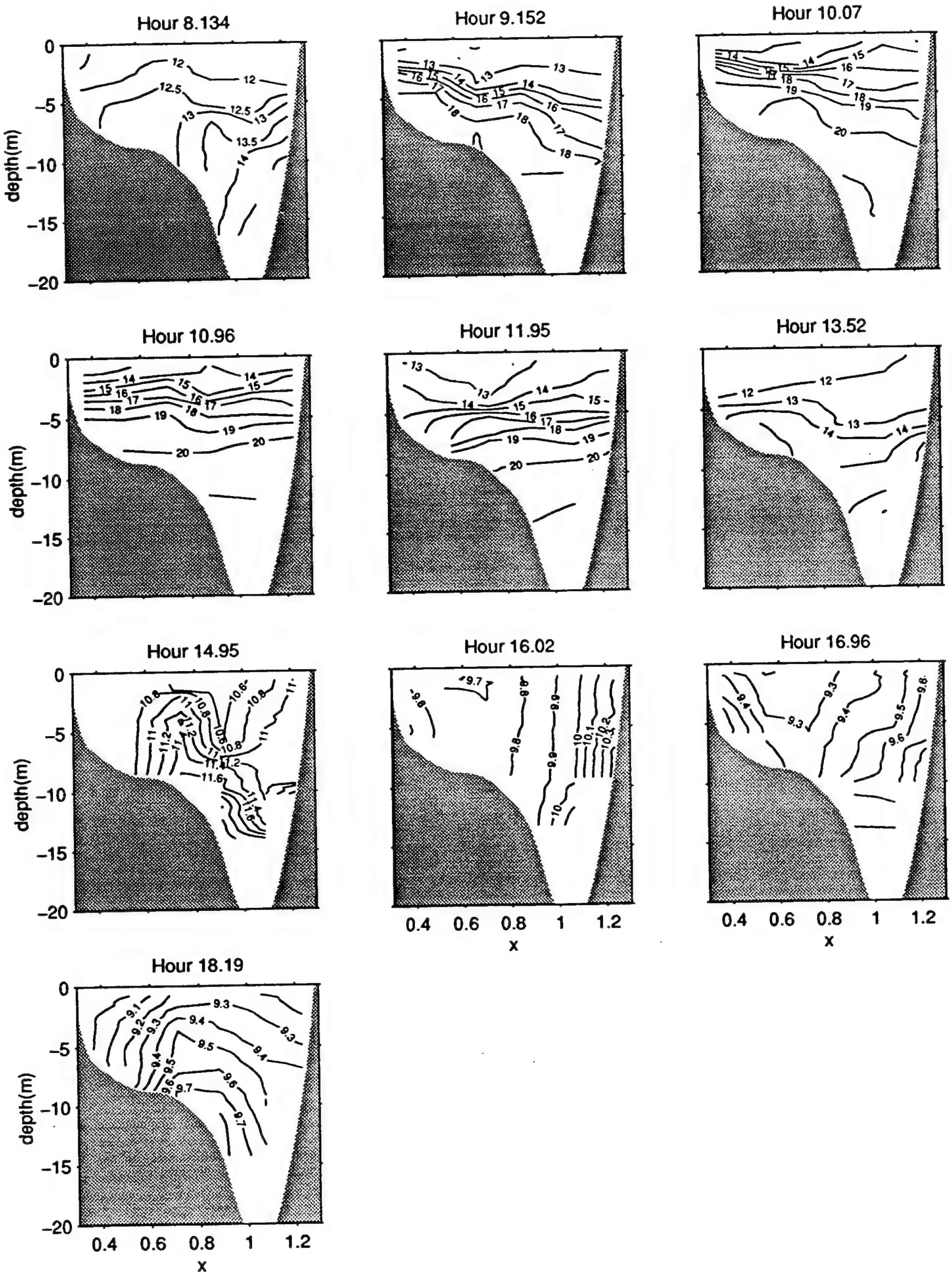


Figure 55a. North transect, salinity contours (psu) on 10/23/95

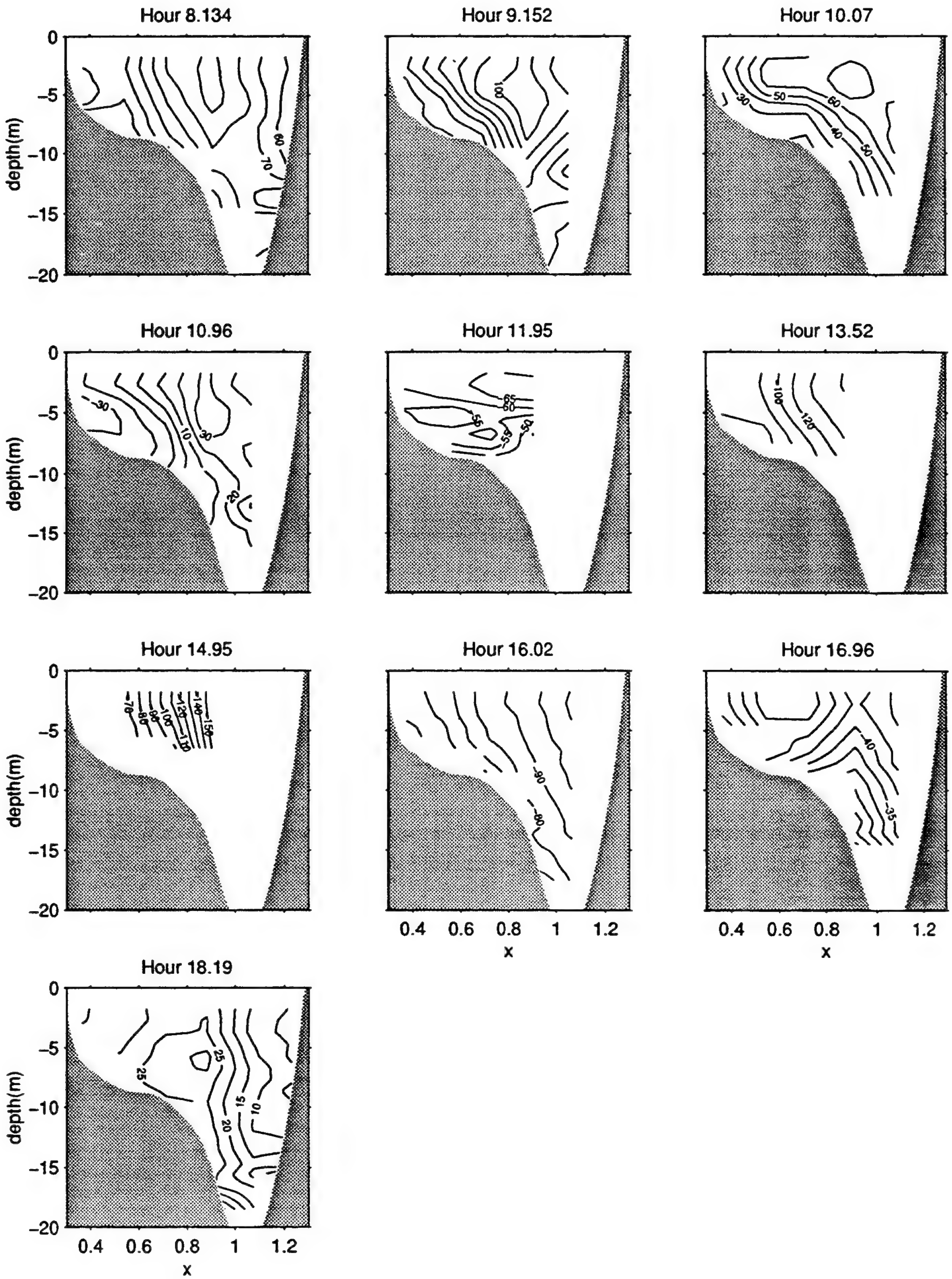


Figure 55b. North transect, velocity contours (cm/s) on 10/23/95

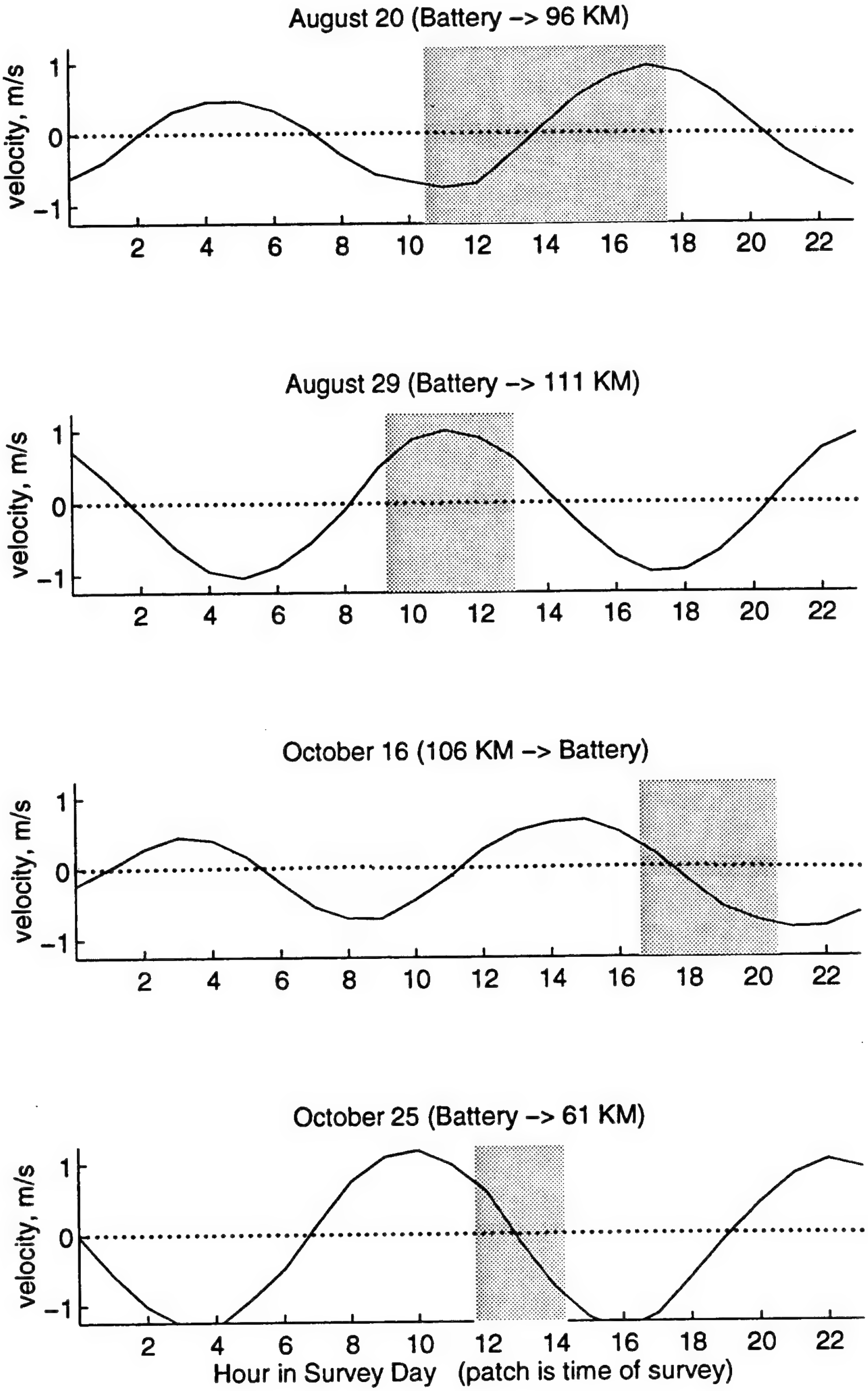


Figure 56. Long Survey Tidal Cycles
(vertically averaged velocity, 8.3 mab, from ADCP)

Figure 57. Long Survey (8/20/95): Temperature & Salinity Contours

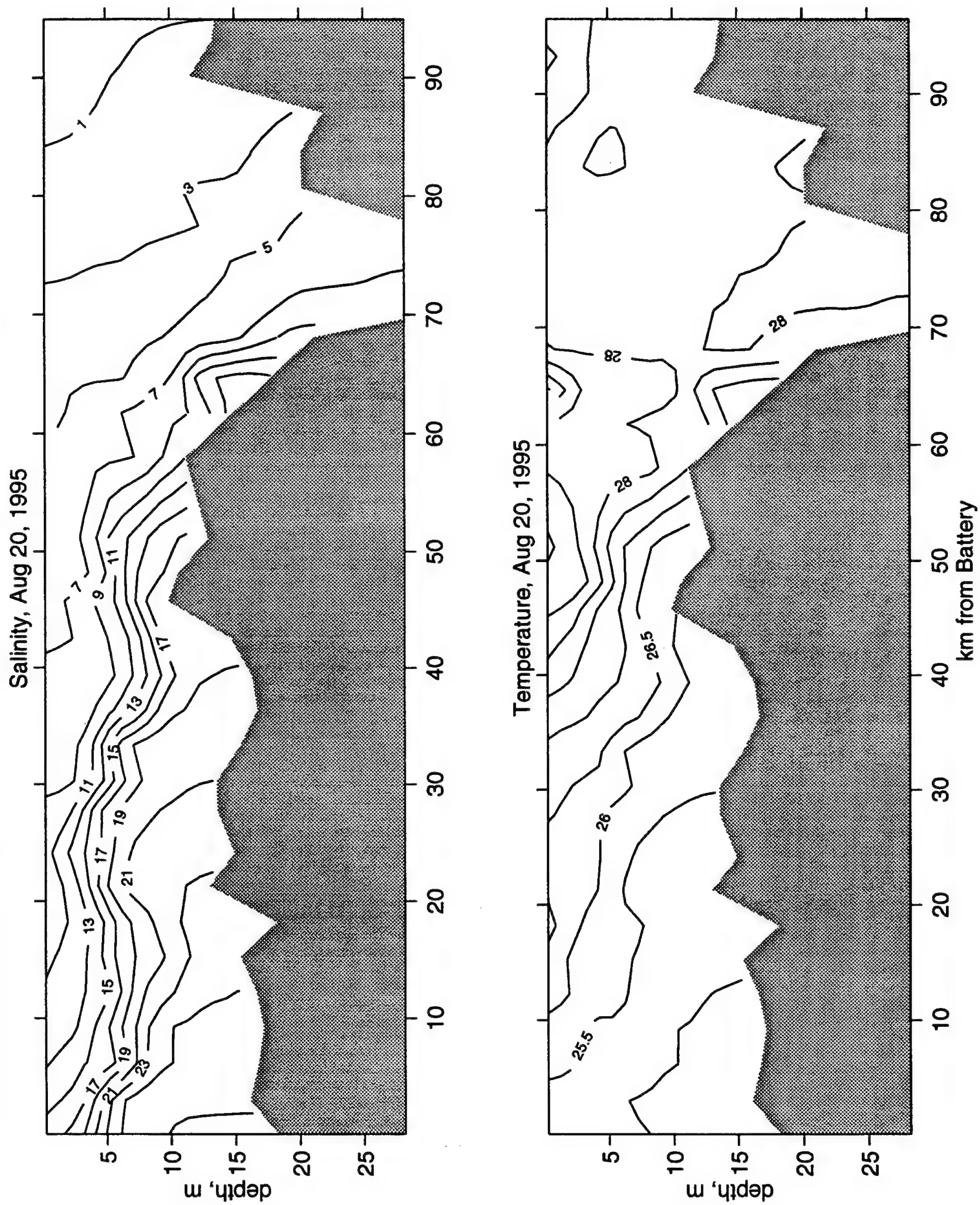


Figure 58. Long Survey (8/29/95): Temperature & Salinity Contours

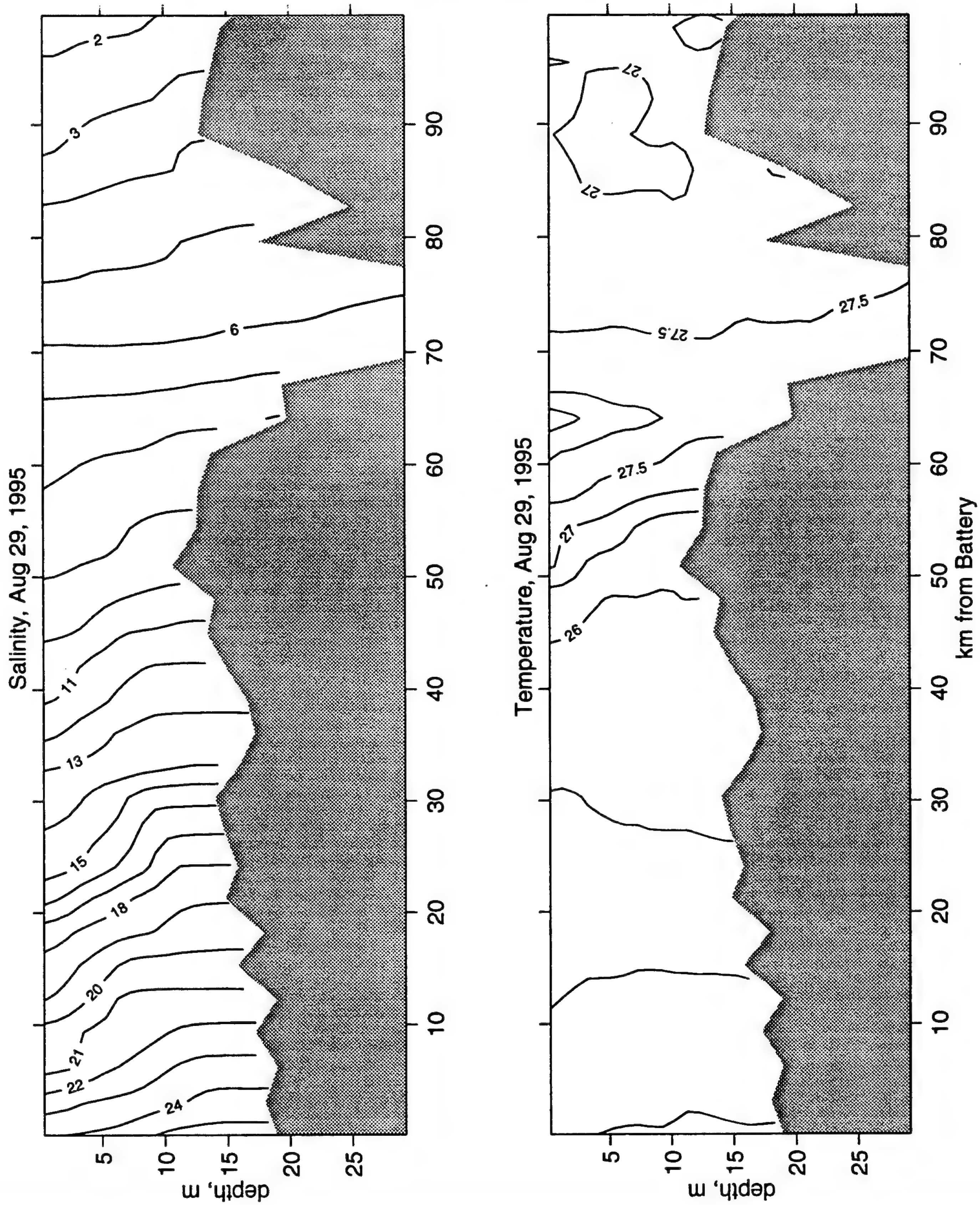


Figure 59. Long Survey (10/16/95): Temperature & Salinity Contours

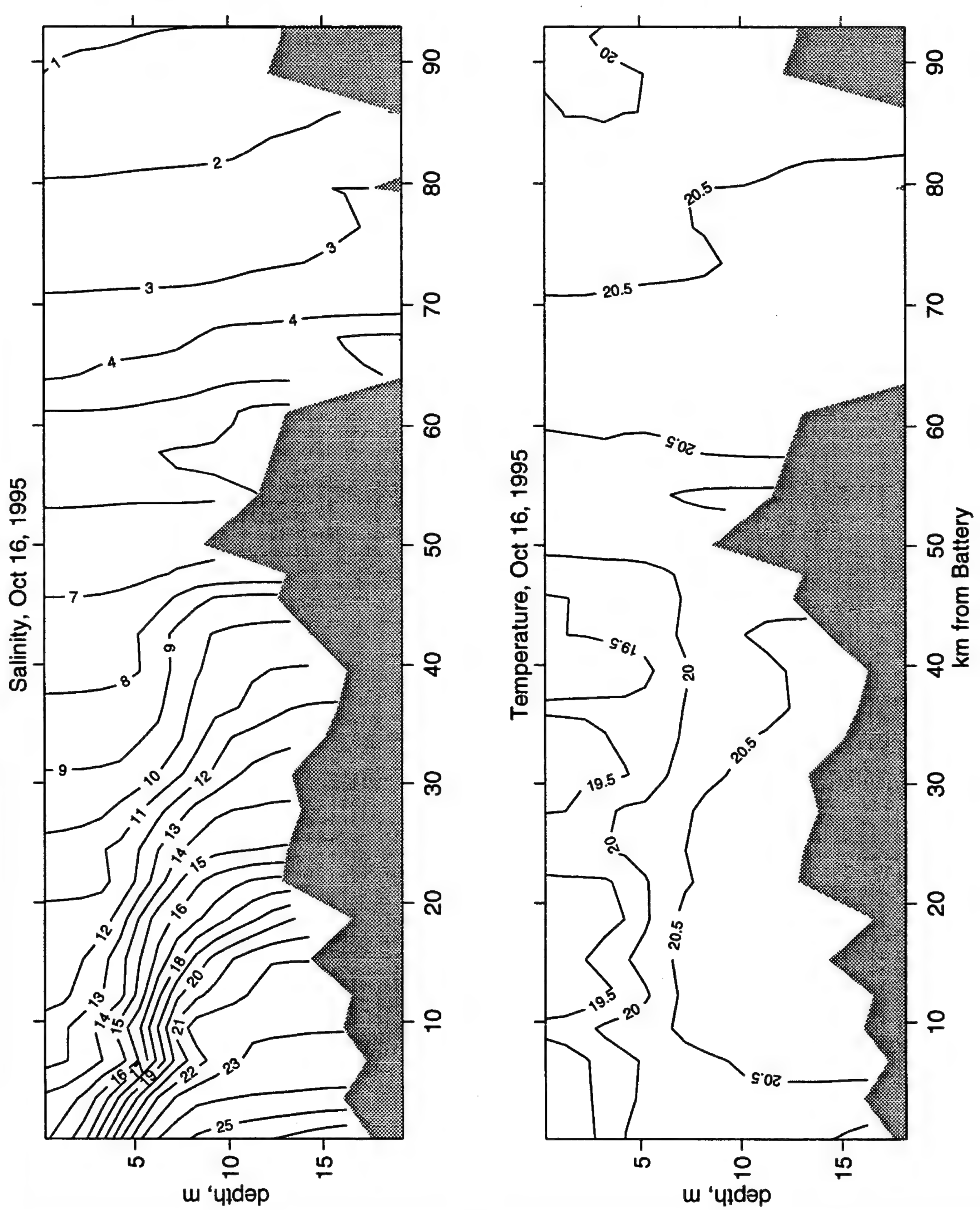
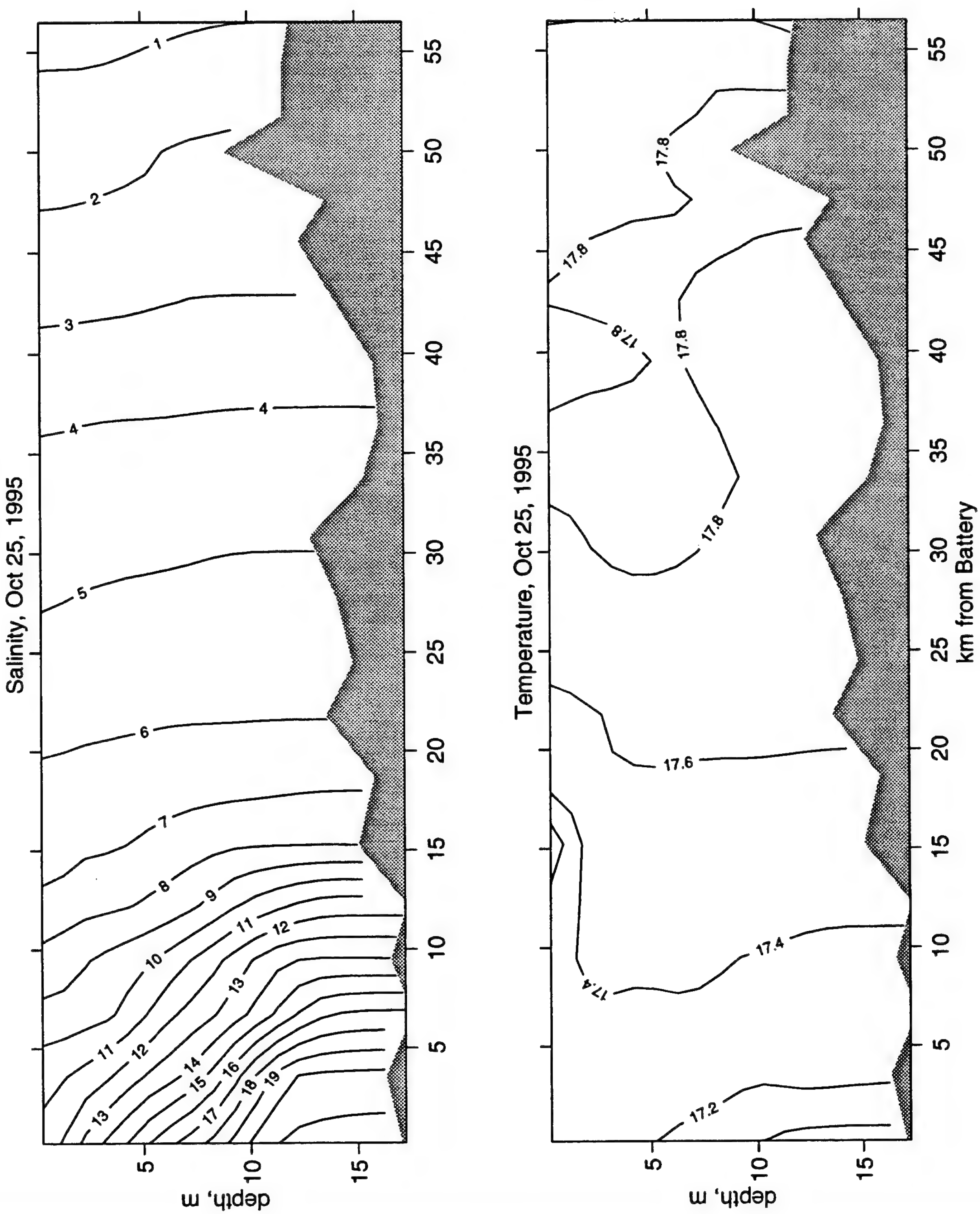


Figure 60. Long Survey (10/25/95): Temperature & Salinity Contours



E. METEOROLOGICAL DATA

Relative humidity, atmospheric pressure, and air temperature are plotted in figure 61a. Figure 61b shows battery voltage and horizontal wind speed. The along-channel velocity (u) and cross-channel velocity (v) are in oceanographic direction, corresponding to the other velocity measurements (+u indicates flow toward the up-channel direction; +v indicates flow toward New Jersey).

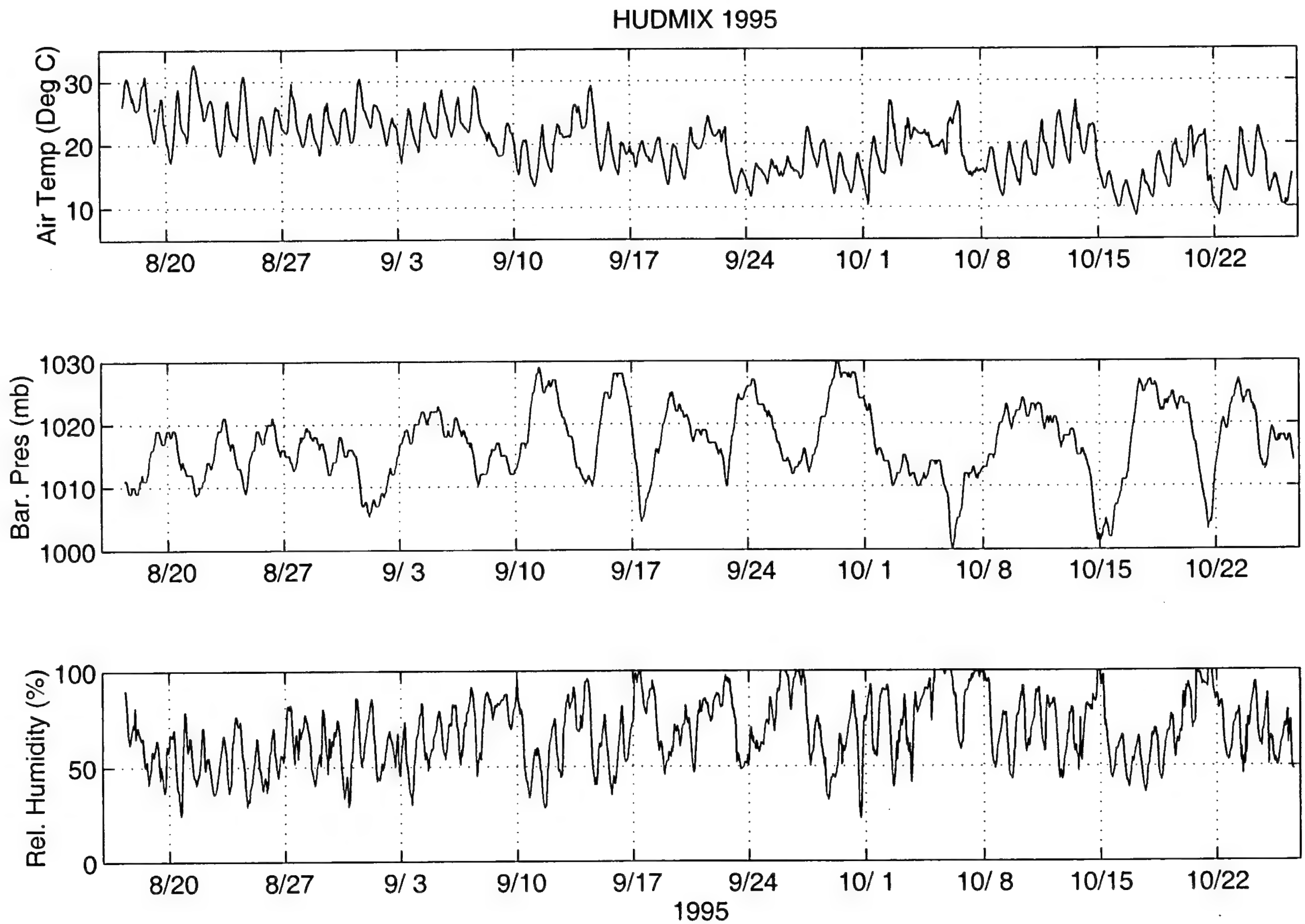


Figure 61a. MET Station Air Temperature, Atmospheric Pressure & Relative Humidity

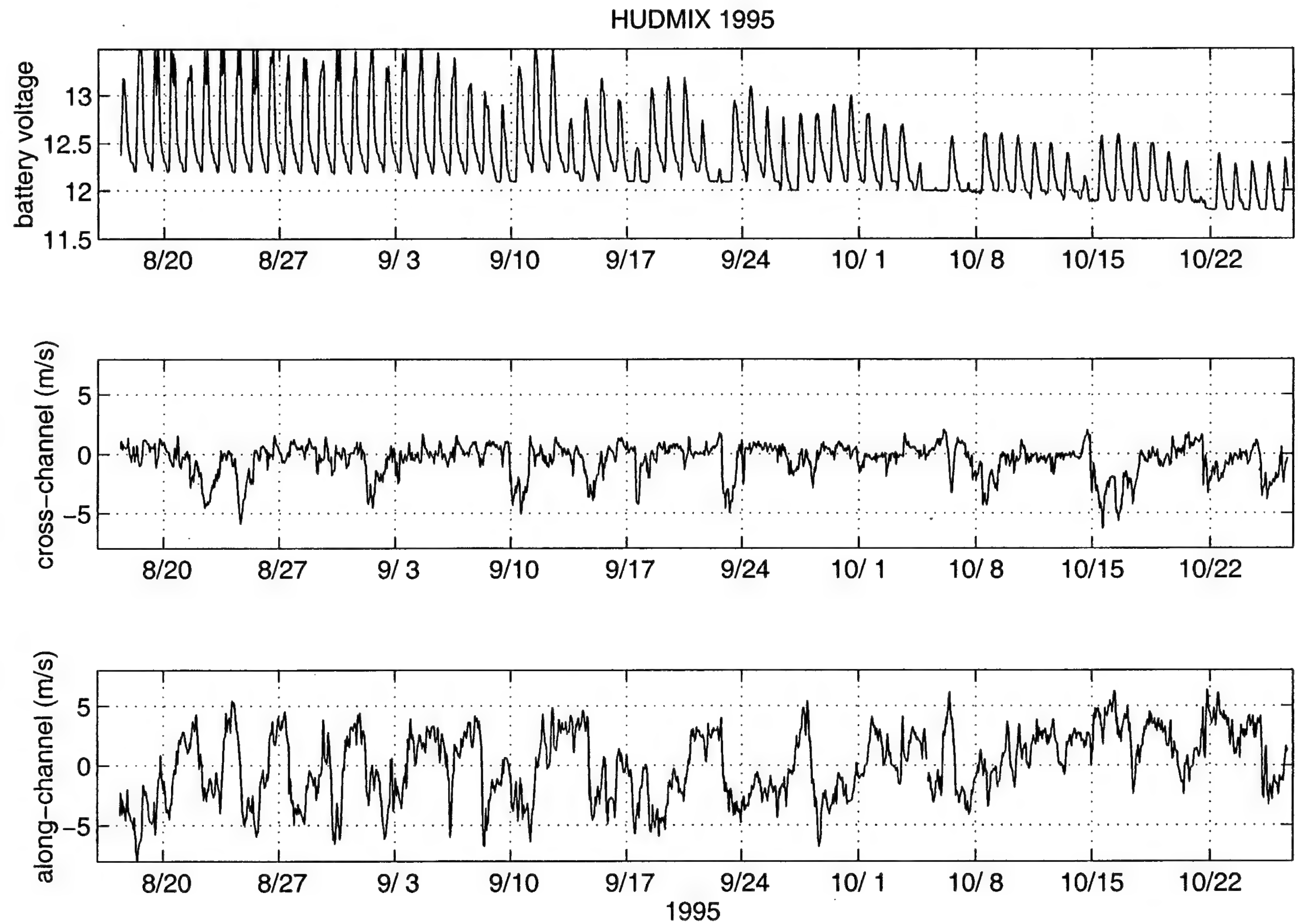


Figure 61b. MET Station Battery Voltage & Horizontal Velocity

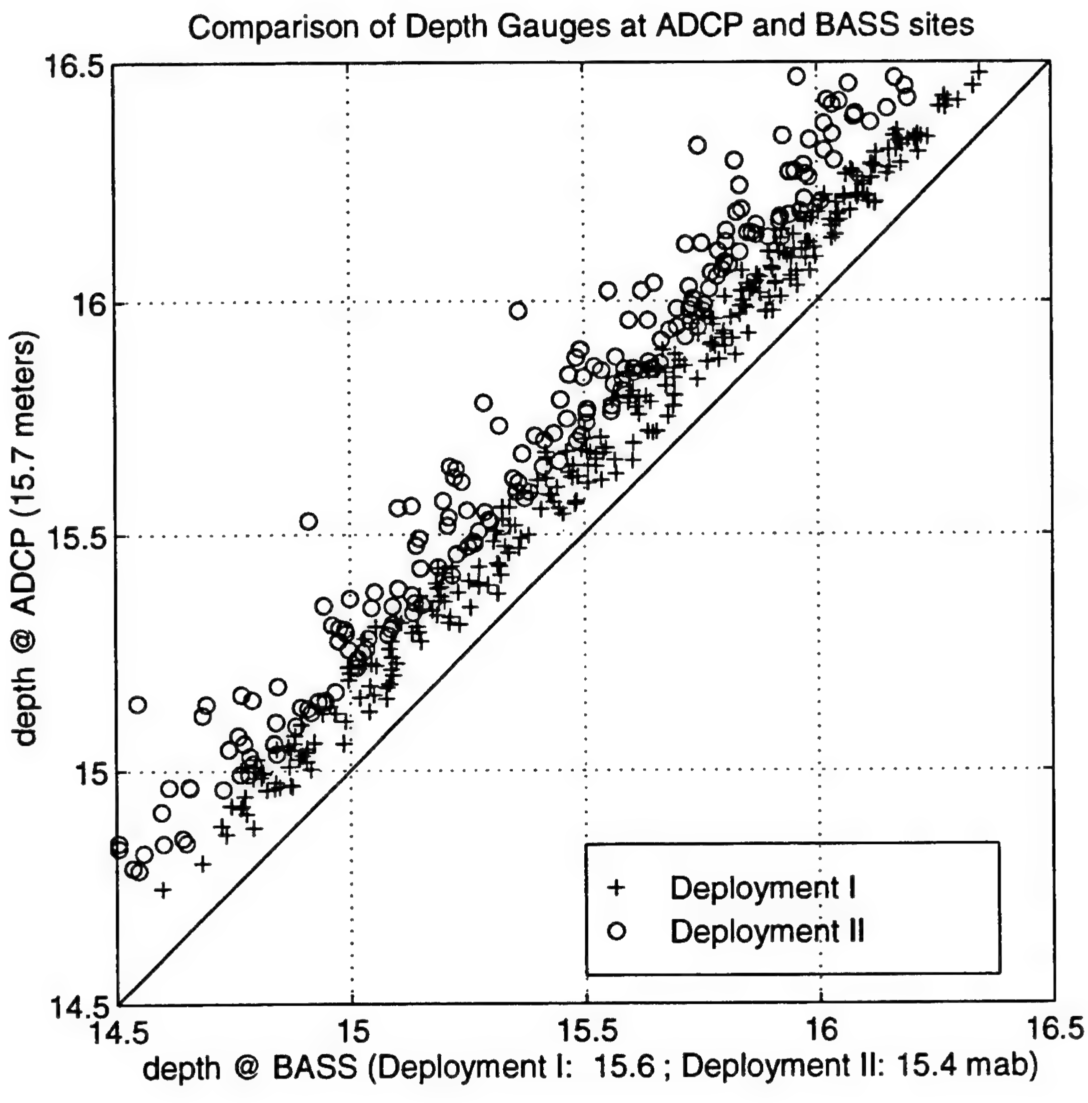


Figure 62. Hourly Averaged Quadrapod depth vs. ADCP depth (meters)

F. DATA CONSISTENCY CHECKS

ADCP with BASS Pressure

A comparison of hourly averaged pressure records from the ADCP tripod are shown with those from the BASS quadrapod for each of the BASS deployments in figure 62.

ADCP with BASS Velocity

Figures 63a (August deployment) and 63b (October deployment) suggest the existence of flow disturbance in the lowest two and the top-most bins of the ADCP profiles (bins 1,2 & 12), possibly from the tripod structures. A shift in velocity between alternate bins can also be seen which resulted from the selection of the smallest bin size (Terry Chereskin, Scripps, personal communication).

Temperature/Salinity Comparisons

Figures 64 and 65 show good agreement of temperature and salinity when comparing the ADCP Seagauge observations with either the lowest Seacat at the Central Mooring or the BASS Seabirds at 1.1 meters above bottom.

MET Station / NDBC Wind Velocity Comparisons

Comparison of the meteorological data from the National Data Buoy Center (NOAA) buoy off Long Island with the HUDMIX wind data, shown in figure 66), suggests that the 79th MET station Weatherpak was obstructed when wind was blowing toward New Jersey (Figure 66).

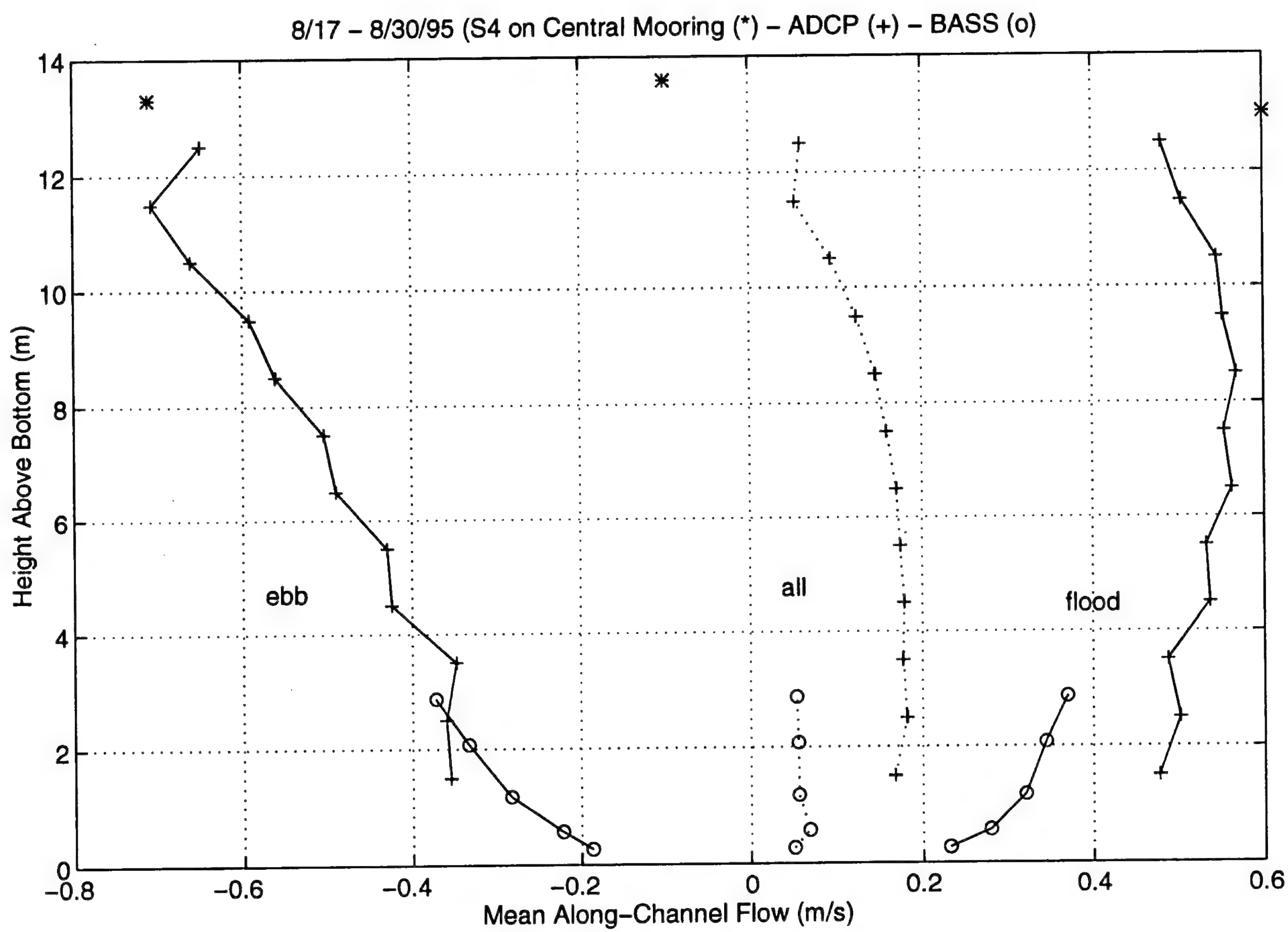


Figure 63a. Comparison of ADCP along-channel velocity with BASS (Deployment I)

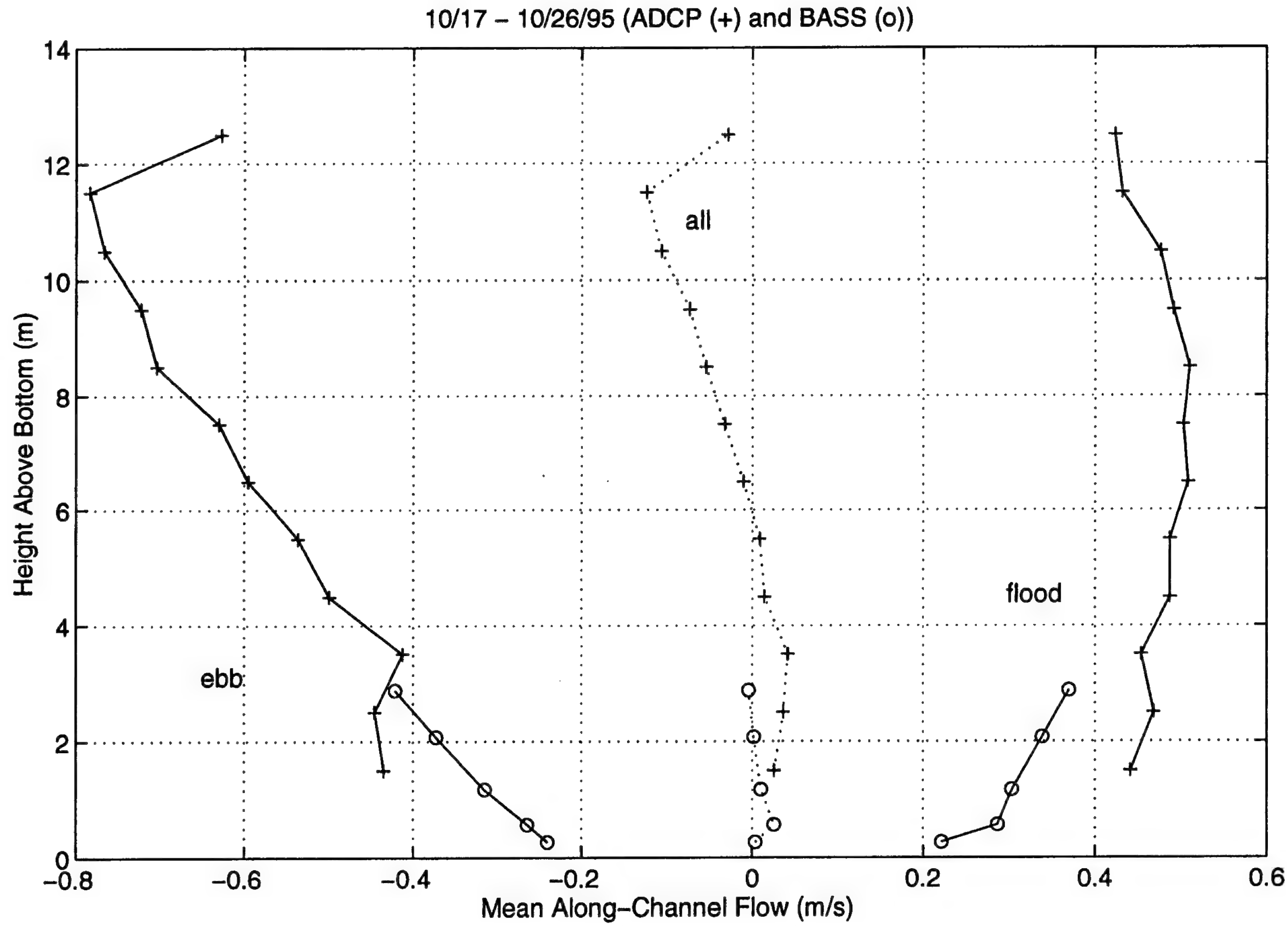


Figure 63b. Comparison of ADCP along-channel velocity with BASS (Deployment II)

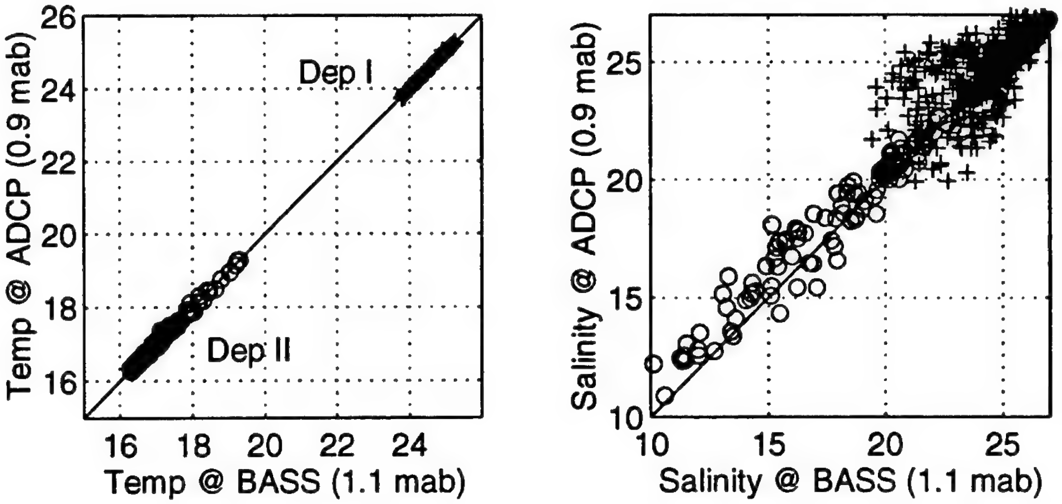


Figure 64. Comparison of Quadrapod Temperature and Salinity (at 1.1 mab) with the ADCP Temperature and Salinity (at 0.9 mab)

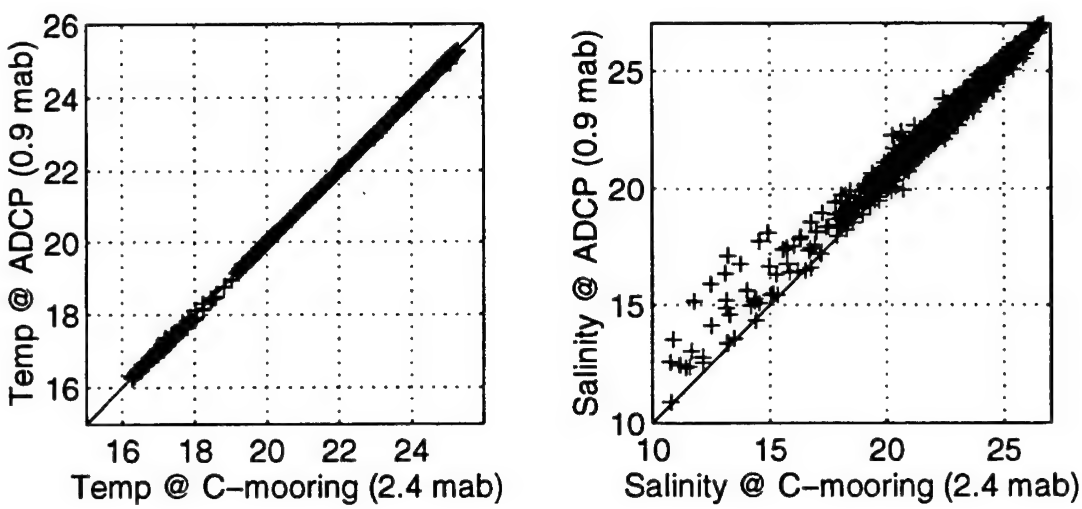


Figure 65. Comparison of C-mooring Temperature and Salinity (lowest sensor) with the ADCP Temperature and Salinity (at 0.9 mab)

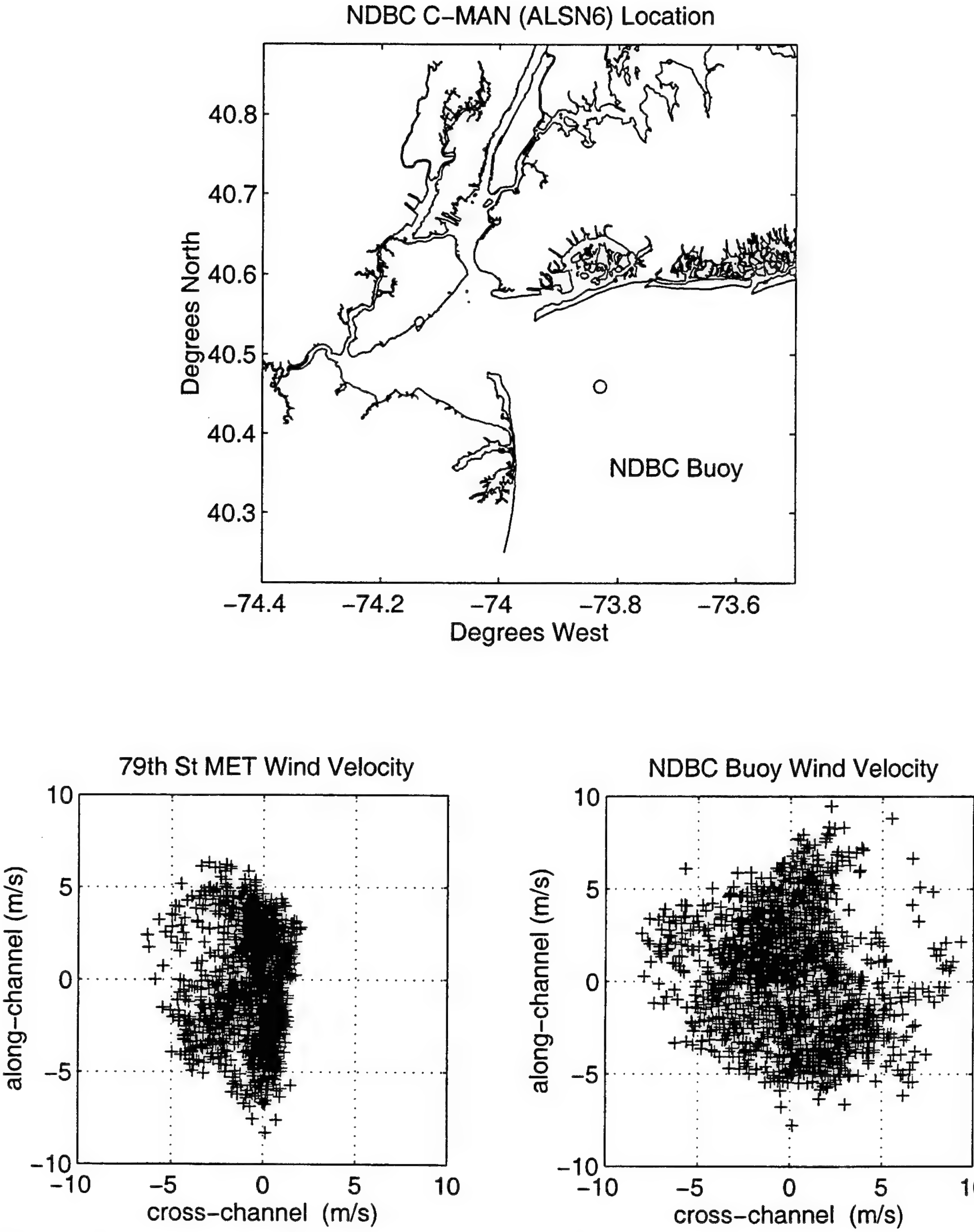


Figure 66. Comparison of MET Station wind velocities with the CMAN NDBC wind velocity (along with site of NDBC buoy).

SECTION VI

FILE DESCRIPTIONS

A. OVERVIEW

This section contains documentation of basic and processed data files, providing a history of the data and a guide for the use of the processed data files.

B. BASS QUADRAPOD DATA FILES

1. Raw Data formats, as recorded by the BASS data logger

Deployment I			Deployment II		
Variable	# variables	bytes/variable	Variable	# variables	bytes/variable
Keyword(AB06)	1	2	Keyword(AB07)	1	2
Timeword	5	1	Timeword	5	1
Travel Time	5	2	Travel Time	10	2
OBS	5	2	OBS	5	2
pitch	1	2	pitch	1	2
roll	1	2	roll	1	2
ACM	20	2	ACM	20	2
compass	1	2	compass	1	2
pressure	1	4	pressure	1	4
SeaBirds	8	2	SeaBirds	8	2
Total bytes/record:		93			103

Data are stored in the order listed above. Timeword is GMT: day, hour, minute, second and counter (0-255). Travel Time, OBS, pitch, roll, ACMs, compass, pressure and SeaBirds are logged as counts.

2. Full Burst Data

Horizontal and vertical velocity were stored in half-day sets. Each half day has two files: v_doy_N.mat and v_vels_N.mat. N represents the unblocking count and can be associated with the date and time of the data by using the associative table in **fnlist.**

In the 'doy' file:

doy - the day in the experiment month (ie., doy=24.5 from the August data set is noon on August 24th). Breaks between bursts can be detected by looking for gaps greater than 2 minutes.

In the 'vels' file:

w - contains the horizontal velocity (m/s) with the real part representing the along-channel flow and the imaginary part representing cross-channel flow (toward New Jersey).
upAC/upBD - represent vertical velocity (m/s)

3. 10 minute Burst Averaged Data

Zmeans: heights of the five BASS sensors, OBS sensors and conductivity cells.

The burst averaged data (every ten minutes) were in Matlab®[1] files as follows:

Vmeans:

wmean,wstd - burst average, std

real part is the along-stream velocity (+ - upstream) (m/s)

imaginary part is the cross-stream velocity (+ - toward NJ) (m/s)

mdoy - day of month (GMT) (August or October)

Vmean2:

emean - number of bad points in each axis within each burst

ccmeanN - six member correlation coefficients where N=1:5 (sensor)

and ccmeanN(:,1) = corrcoeff(u,v)
ccmeanN(:,2) = corrcoeff(u,wac)
ccmeanN(:,3) = corrcoeff(u,wbd)
ccmeanN(:,4) = corrcoeff(v,wac)
ccmeanN(:,5) = corrcoeff(v,wbd)
ccmeanN(:,6) = corrcoeff(wac,wbd)

where:(u = along-channel flow; v = cross-channel flow;
wac = vertical from A/C axes; and wbd = vertical from B/D)

wACmean(std) = burst average(std) of vertical velocity from axes A/C

wBDmean(std) = burst average(std) of vertical velocity from axes B/D

(NOTE: When axes are reconstructed, wAC may be identical to wBD and the names may be misleading. Eg., if axis A is reconstructed, wAC is actually wBD.)

TSmeans:

tmean, smean, cmean - burst average temperature (degrees Centigrade), salinity (o/oo),conductivity (Siemens/m)

tstd,sstd,cstd - standard deviation within burst of temperature, salinity, conductivity

temean - errors flagged within each burst (temperature, salinity, conductivity)

Pmeans:

pmean(std) - burst average (std) of pressure (m) above sensor (1.56 mab)

pemean - errors flagged within each burst

PRCmeans:

cmean - mean compass reading (degrees) (updated hourly)

pmean - mean pitch (degrees) (in A-C direction)

rmean - mean roll (degrees) (in B-D direction)

pstd,rstd - standard deviation of pitch, roll within burst

Omeans:

omean - mean optical backscatter (counts) within burst with baseline removed

ostd - standard deviation of backscatter within burst

oemean - errors flagged within each burst

ORmeans:

(as above, but contains raw counts)

---

[1] Mathworks, Inc., Natick, MA 01760

4. Hourly Averaged Data

The hourly averaged data are stored in one file for each deployment:

hudmix_b1(8/95):

jdbass - day of year (EDT)
ubass - hourly average up-stream velocity (m/s)
vbass - hourly averaged cross-stream velocity (m/s) (+ toward New Jersey)
ustd - hourly average of standard deviation within bursts in the along-stream direction (m/s)
vstd - hourly average of standard deviation within bursts in the cross-stream direction (m/s)
tmean, smean - hourly average temperature (degrees Centigrade), salinity (o/oo)
omean - hourly average optical backscatter (processed counts)
depth - hourly average depth (m) from pressure

hudmix_b2 (10/95):
(same as above but jdbass was called jdbass2, etc.)

C. MET, TRIPOD & MOORED DATA FILES

1. Raw Data Files

For the purposes of this report, we have described the ASCII files which were converted from the binary files noted in parentheses.

ADCP:ASCII files HASC.NNN, where NNN=001-047, contain data which were converted from binary and scaled, corrected for pitch and roll, and converted to earth coordinates using adcpread.m. The format of the HASC files is in Table 4-2 (pp. 4-10 to 4-19) of the ADCP Manual (RD Instruments - March, 1991).

S4s: ASCII files hudM.asc, where M=mooring (c-f), can be read by reads4.m. Each file contains a header and description of each field.

Seagauges:

ASCII files hudMsgN.tid, where M is mooring(a-f) and N is the Seagauge ID, contains a sample id, date, time, pressure(psia), temperature (deg C), relative humidity (%), conductivity (Siemens/meter). These data can be read using readsg.m.

Seacats:

ASCII files:
(NOTE: hude_bot model 883 & hudetop is also
model 883 one date 10/31 other 11/3 but
data are the same)
hudc70.cnv: C mooring / SN 70
hudc71.cnv: C-mooring / SN 71
hudc72.cnv: C-mooring / SN 72
hudc73.cnv: C-mooring / SN 73
hudc884.cnv: C-mooring / SN 884
hude_bot.cnv: E-tripod
hudetop.cnv: E-mooring (seems to be same data as e_bot, but diff date)
hud68e.cnv: E-mooring / SN 68
hudfbot.cnv: F-tripod
hudftop.cnv: F-mooring

ASCII fields are described in headers.
These data can be read using readsc.m.

Met: ASCII file hudmet.asc contains unprocessed met data: date, time, wind speed (m/s), direction(degrees from north), sd,gust,lc, atmospheric temperature (deg C), barometric pressure (mbars) relative humidity (%), and battery voltage (V).

2. Hourly Averaged Data

Data were smoothed and stored as syncronized hourly averages in file **hudmix_m.mat,** which is summarized below:

jd - day of year (0.5 is noon on 1/1) (EDT)

at: air temp (deg C) from met station
bp: baro pressure (mbars) from met station
rh: relative humidity (percent) from met station
vbat: voltage, battery (can indicate sun coverage) from met station
uwind,vwind: wind speed (m/s) from met station (oceanographic flow)

t: temperature (deg C) from tripods and moorings
s: salinity (deg C) from tripods and moorings
c: conductivity (deg C) from tripods and moorings
p: pressure (dbars) from tripods and moorings
us4,vs4: velocity (m/s) from S4 current meters
obs: optical backscatter

Array descriptions:

s4_name:	s4_depth(m):	ts_name:	ts_depth(m):
1 c surface	3.2	1 atripod	17.0
2 d deep	19.5	2 btripod	17.0
3 e deep	7.2	3 cmooring--s4	2.7
4 f deep	6.5	4 cmooring--c1	4.3
		5 cmooring--c2	6.3
p_name:	p_depth(m):	6 cmooring--c3	8.3
		7 cmooring--c4	10.3
1 atripod	17.0	8 cmooring--c5	12.3
2 btripod	17.0	9 adcptripod	15.0
3 cmooring--s4	2.5	10 dtripod	20.0
4 cmooring--c5	12.3	11 etripod--top	1.0
5 adcpmooring	15.0	12 etripod--bottom	7.7
6 dmooring	19.5	13 ftripod--top	1.0
7 fmooring--bot	8.4	14 ftripod--bottom	8.0

ADCP velocity data are stored in **adcp2hour.mat.**
The variables urn and vrn represent along-channel (up-channel) and cross-channel flow (toward New Jersey), respectively, and are in meters/second. The heights of the fifteen bins are 1.5 to 15.5 at 1 meter intervals. Zeit is the day of the year (EDT), and is identical to 'jd' (hudmix_m.mat).

D. SHIPBOARD DATA

Shipboard data are stored as hud95NN.mat, where NN is the survey day number (3-25) as given in Table 3.

Description of the variables in the shipboard data files:

varname - name of file

jd - day of year (0.5 is noon on 1/1) (EDT)
hour - local time (EDT)

lat, lon - latitude, longitude (decimal degrees)

y - along channel position in km from the Battery, where river joins New York Harbor
x - across channel position in km the New Jersey Shore
z - depth in meters, z=0 at water surface

depth - Bottom depth calculated using depth at which ctd touched bottom

s - Salinity in psu
t - Temperature in degrees Celsius
conc - Sediment concentrations in mg/L, OBS data converted using sed_conc.m
u - velocity in cm/s, positive in flood (obtained by interpolating adcp data and rotating data into direction of maximum variance using rotate.m)

thetarot - degrees u rotated in counterclockwise direction, based on E 1st, N 2nd

Variable names for day 7 and 9:

linenum - line number (every line has three along channel transects)
xpos- - defines transect, 1=NJ side, 2= middle, 3=NY side

Variable names for day 10:
linenum - line number (every transect identified with a seperate line number)
transect - index, across channel transects= 1, along channel transects= 2

Variable names for day 11:
linenum - line number (each line number has across and along channel transect)
transect - index, across channel transects= 1, along channel transects= 2

SECTION VII

ACKNOWLEDGEMENTS

The success of the HUDMIX project can be contributed to a great many people. The authors would like to express their appreciation to:

Harmut Peters (SUNY, Stony Brook) and Gail Kineke (WHOI), for their collaboration;

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SECTION VIII

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16. Abstract (Limit: 200 words)

A field study was performed in the lower Hudson River, a partially mixed estuary with a relatively simple geometry (Figure 1), between August and October of 1995. The objectives of the study were (1) to quantify and characterize the turbulent transport of momentum and salt, and (2) to relate the turbulent transport processes to the local and estuary-wide dynamics.

The measurement program consisted of fixed and shipboard components. At a central site, a moored array of temperature-conductivity sensors and optical backscatter sensors (OBS), a bottom-mounted acoustic Doppler current profiler (ADCP), and a bottom-mounted array of acoustic travel-time current sensors (BASS), temperature-conductivity sensors, and OBS sensors resolved the vertical structure of velocity, salinity and turbidity and the near-bottom turbulence structure. Moored and bottom-mounted velocity, temperature, conductivity and pressure sensors at five secondary sites quantified the spatial and temporal variability of velocity, salinity and bottom pressure. Shipboard measurements with an ADCP and a conductivity-temperature-depth (CTD) profiler, accompanied by an OBS sensor, resolved the spatial structure and tidal variability of velocity, salinity and turbidity along several cross-channel and along-channel transects.

This report describes the measurements in detail. Section II describes the instrumentation, Section III describes the deployment and sampling schemes, Section IV describes the data processing, and Section V is a summary of plots of selected data. Section VI documents the data files and Sections VII and VIII give acknowledgments and references.

17. Document Analysis a. Descriptors

stress
salt flux
mixed estuary

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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